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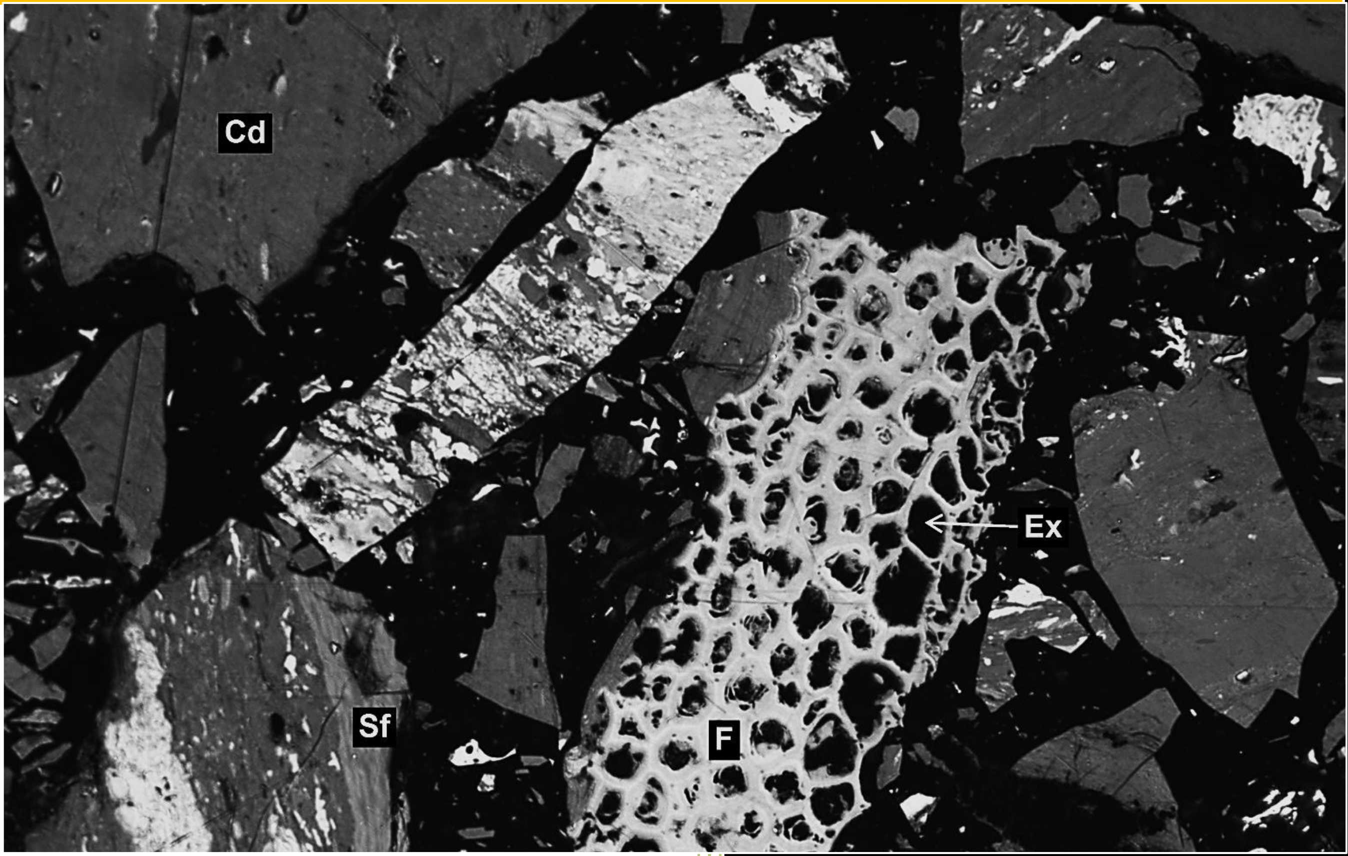
PALEOENVIRONMENTS OF COALS USING ORGANIC PETROGRAPHY AND THEIR RELATIONSHIP WITH PHYSICOCHEMICAL PROPERTIES, GUADUAS FORMATION, CHECUA-LENGUAZAQUE SYNCLINE



Universidad Pedagógica y Tecnológica de Colombia

COLCIENCIAS
Ciencia, Tecnología e Innovación

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SOGAMOSO, BOYACÁ
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RESEARCH PROJECT TO OBTAIN THE TITLE OF GEOLOGIST ENGINEER

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Sogamoso, Febrero 21 de 2016

Señores:
COMITÉ DE CURRÍCULO
ESCUELA INGENIERÍA GEOLÓGICA
SEDE SECCIONAL SOGAMOSO U.P.T.C

Cordial saludo.

Por medio de la presente nosotros, **JUAN SEBASTIAN GÓMEZ NEITA Y MAYRA DAYANA LÓPEZ CARRASQUILLA** estudiantes en terminación académica, nos dirigimos a ustedes para poner en consideración la asignación de jurados del trabajo de investigación denominado: PALEOENVIRONMENTS OF COALS USING ORGANIC PETROGRAPHY AND THEIR RELATIONSHIP WITH PHYSICOCHEMICAL PROPERTIES, GUADUAS FORMATION, CHECUA-LENGUAZAQUE SYNCLINE.

Agradecemos su atención y gentil colaboración.

Atentamente

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COMITÉ DE CURRÍCULO
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Cordial saludo.

Por medio de la presente yo, **SANDRA ROCIO MANOSALVA SÁNCHEZ,** me dirijo a ustedes para poner en consideración la asignación de jurados del trabajo de investigación denominado: PALEOENVIRONMENTS OF COALS USING ORGANIC PETROGRAPHY AND THEIR RELATIONSHIP WITH PHYSICOCHEMICAL PROPERTIES, GUADUAS FORMATION, CHECUA-LENGUAZAQUE SYNCLINE, realizado por los estudiantes **JUAN SEBASTIAN GÓMEZ NEITA Y MAYRA DAYANA LÓPEZ CARRASQUILLA.**

Agradezco su atención y gentil colaboración.

Atentamente

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SANDRA ROCIO MANOSALVA SÁNCHEZ
DIRECTORA DEL PROYECTO

ACCEPTANCE NOTE

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ABSTRACT

The coal is an important mineral resource used worldwide in the production of coke and thermic energy, the Checua-Lenguazaque syncline in the major zone where coals are exploited in the central zone of Colombia (Cundinamarca and Boyacá provinces) with this purpose; so understand their origin and processes that affected their quality is very important to development a sedimentary model including the thermal history and the depositional environment; these aspects can be evaluated in coals with the use of the organic petrography through the reflectance of vitrinite and maceral reading tests.

Vitrinite reflectance indicated that rank increase with depth causing textural, physical and chemical changes along the coalification process varying the content of moisture, volatile matter and fixed carbon. The samples were classified with the ASTM D388-12 norm (High volatile bituminous coals to low volatile bituminous coals) and the ISO 11760 norm (Bituminous coals type C to bituminous coals type A). The Baker equation allowed the determination if the achieved peak temperature for each coal and determine the thermal gradient in the basin concluding that there were different paleogeothermal gradients along the area being more intense in the Samacá section (100°C/Km) than Sutatausa (52°C/Km) and Guachetá (82°C/Km) sections.

The maceral reading showed a predominance of macerals of the vitrinite group indicating a good preservation of precursor organic matter, and it allowed the calculate of petrographic indices (GI, TPI, Diessel diagram) (VI, GWI, Calder diagram) to stablish the possible depositional model indicating that coals were deposited in three major environments: Marshes, wet forest swamps and back barrier zones with a fluctuating water level as result of marine incursions increasing the content of framboidal pyrite and calcium; likewise nutrients of peatbog came from rain falls according with the hydrological behavior. The ternary diagrams proposed by Mukhopadhyay and Singh & Singh, give and idea of the predominant vegetation (Forest or reeds), water level, oxic conditions and degradation, showing a preferential behavior to a transition of forest and reed swamps with a medium water level and anoxic conditions, then the paleoenvironments is directly related with the ash and sulfur contents in coals in the study area and they present a correlation with the chemistry water and its level in the peatbog.

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DEDICATION

Thank God for giving us life, love and constancy to work for our dreams; Thanks to our parents *Roberto Gomez, Elizabeth Neita, Mario López and Deidy Carrasquilla* for accompanying us in each one of our steps and guiding us with example and value; to our families, colleagues and managers.

To teachers for their teaching, patience and love for the geology, thank them for joining us on this long journey and providing us with solid foundations to deal the real life. To our director of geological engineering school, the engineer *Wilson Naranjo* for being an image of responsibility and kindness, to the engineer *Jorge Mariño* for his dedication, and to the teachers *Mercedes Perez, German Herrera, Hector Fonseca* and *Angela Leguizamon* for their support. Thanks to the engineer *Sandra Manosalva* for allowing us to work alongside her, to direct us and to teach us, by her humility and understanding,

Thank UPTC and COLCIENCIAS for linking us to this project; and learn from the best professionals.

Juan Sebastián and Mayra Dayana.

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1. CHAPTER ONE: PRESENTATION

1.1. INTRODUCTION

The research Project titled "*Caracterización petrográfica y fisicoquímica de los carbones coquizables de la Formación Guaduas bases para el modelamiento geológico y optimización del recurso*" as contract 070- UPTC-COLCIENCIAS, has allowed the development of different themes about coals and their implications like geological and economical resource in Colombia. For this study were recollected sixty four (64) samples of coal using the channel method (ASTM D2234/ D2234M-16) in the front of operation of different underground mines along the western flank of the Checua-Lenguazaque syncline in the localities of Cundinamarca and Boyacá, in the Sutatausa, Guachetá and Samacá blocks.

The maceral reading showed that the coals are composed mainly of macerals of the vitrinite group with percentages between 51.40% - 87.00%, followed by the inertinite group (5.40% - 43.80%), liptinite (0.20% - 14.00%), and mineral matter (0.40% - 18.0%). The random vitrinite reflectance varied between 0.69% and 1.60%; indicating bituminous coals C to bituminous coals A, according with the ISO 11760 norm. With the determination of the organic components was used the facies model implemented by Diessel 1992 and different ternary diagrams proposed by Sing & Sing to determine the possible environments of accumulation.

According with the study, the coals of Guachetá and Samacá blocks were deposited in environments of protected areas for barriers and marshes mainly, while the coals of the Sutatausa block extended into wet-forest swamps. Table water although variable, covered the peat bog which favored the preservation of organic material against oxidation, so the environment has an important implication in the physical properties of coals like ash and sulfur content while the range of coal will determine another properties like volatile matter, moisture and fixed carbon.

1.2. PROBLEM STATEMENT

Different studies have been carried out on the coals of the Checua - Lenguazaque syncline with two main purposes: Research and economic exploitation; nevertheless, it is necessary to integrate the pertinent information and to create sedimentary models that allow understanding the depositional environment of these coals and how this one influences their physicochemical properties.

Using organic petrography is possible determine depositional environments, type of vegetation and prevailing conditions in the peatbog in the moment of deposition; this technique will be used to the Guaduas Formation coals (Maastrichtian to Paleocene) in the Checua-Lenguazaque syncline in its three sections, Sutatausa, Guachetá and Samacá.

1.2.1. Problem formulation.

Is it possible by the petrographic characterization of the coal seams on the western flank of the Checua-Lenguazaque syncline to determine paleoenvironments and their relation to physicochemical properties?

1.3. JUSTIFICATION

It is proposed to identify how the petrographic characterization in coals allows the determination of paleoenvironments and how these modify the physicochemical properties cause lateral and vertical changes in a stratigraphic succession. The study was made in the western flank of the Checua-Lenguazaque syncline in the Guaduas Formation rocks (Upper Cretaceous to Paleocene) in the provinces of Cundinamarca and Boyacá in Colombia.

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1.4. LITERATURE REVIEW

Different studies were made in different countries to determine paleoenvironments using organic petrography however it is a recent technique and the applied methodology can vary according with the sampled coals and the basin in which they were recollected, so it is very important the knowledge of the basin where coals are present. The following summary shows the relevant studies using organic petrographic to determine depositional environments and studies of the basin where was realized this study.

Diessel (1986) made an investigation in the Sydney basin in Australia and he proposed a diagram based in tissues preservation index and the gelification index to determine the possible paleoenvironment where were deposited the coals in the basin.

Goodarzi (1986) studied the Hat Creek Coal deposit No. 1, British Columbia and he proposed a ternary diagram to define the oxic and anoxic conditions in the formation of coals and the importance of the mineral matter influence in their environment.

Mukhopadhyay (1986) analyzed the coal lignites in Texas, USA and he proposed a ternary diagram based in the maceral aggrupation to determine the most probable environment with three options, forest swamp, red marsh and dry conditions.

Calder, Gibbing, & Mukhopadhay (1991) interpreted coal samples in the Cumbberland Basin, Nova Scotia and they proposed a diagram based in vegetation index and the groundwater index to determine the predominant type of vegetation and the phreatic level in the peatbog.

Alves & Ade (1996) applied the organic petrography in the Candiota coal field (Paraná Basin) in Brazil to make a depositional model concluding that rocks were deposited in three systems: low level sea, transgressive and high level sea. The Coals seams were deposited in a barrier-lagoon system in this work.

Singh & Singh (1996) (2000) studied the Indian coals and they proposed two ternary diagrams, the first one indicating the oxic and anoxic conditions and the flooding processes; the second one based in the proportion of the liptinite group macerals determine the water depth and possible vegetation in the moment of deposition.

Jiménez, Martinez Tarazona, & Suárez Ruiz (1999) used the organic petrography to determine the paleoenvironmental conditions in Puertollano coals (Spain) concluding the importance of collodetrinite in coals as a signal of higher decomposition and the Ph influence.

Guatame & Sarmiento (2004) applied the organic petrography in the same basin of this study (Eastern mountain range Basin) in Colombia. They concluded that samples of this area were deposited in transitional environments with high influence of marine incursions.

Mejia Umaña, Convers Gomez , & Gonzales Casallas (2006) analyzed the coals samples (Guaduas Formation) of the Sueva syncline in Cundinamarca, Colombia and the concluded that seams were deposited in a lower interdeltaic plain with marshes and bogs; with the open sea in the west.

Misiak (2006) used the 308 coal seam in the Upper Silesian Coal Basin, Poland to apply the organic petrography, he realized a microprofile and he concluded the importance of water surface in the mineral matter content

Amaya (2009) studied the Guaduas Formation in the Cundinamarca and Boyacá provinces establishing 12 lithofacies associated with four depositional environments (Coastal lagoons, tidal flats, alluvial flood plains and meandering channels).

Barrera (2016) used the vitrinite reflectance data of this study to determine the paleogeothermal gradient in the Checua-Lenguazaque syncline concluding that in Sutatausa was 52°C/km, in Guachetá 82°C/km and in Samacá 100°C/km.

Gomez Neita, Lopez Carrasquilla, Manosalva Sánchez, & Naranjo Merchán (2016) used the same data to determine paleoenvironments of the coals from this study based in the maceral reading concluding that the seams were deposited mainly in marshes, wet forest swamps, strand plains and back barrier zones.

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1.5. OBJECTIVES

1.5.1. General objective.

- Make the petrographic characterization of the coal seams in the western flank of the Checua - Lenguazaque syncline to determine the paleoenvironments and the relationship of these ones with physicochemical properties.

1.5.2. Specific objectives.

- Collect preexisting information about the coals of the Guaduas Formation (Maastrichtian to Paleocene) on the western flank of the Checua - Lenguazaque syncline.

- Characterize petrographically the samples of coal (Random average reflectance of vitrinite and maceral composition).

- Determine the physicochemical properties of coals by proximate analysis and sulfur content.

- Classify coals according to ASTM D388-12 and ISO 11760 norms.

- Establish depositional environments of coals based on the maceral distribution (Petrographic indices, ternary diagrams and schemes).

- Determine the variation of the physicochemical properties of coals according to the depositional environment.

1.6. METHODOLOGY

The methodology of work is shown in the figure 1; it was divided in seven stages according with the evolution of work and the recollection of data.

STAGE 1: COLLECTION OF SECONDARY SOURCE INFORMATION

- Collection of information of the study zone (Ingeominas, companies and articles).
- Search for information in databases.

STAGE 2: SAMPLING AND FIELDWORK

- Sampling of coals.
- Elaboration of stratigraphic columns.

STAGE 3: CHARACTERIZATION OF COAL SAMPLES (MEDIUM REFLECTANCE OF VITRINITE , MACERAL COMPOSITION AND PROXIMATE ANALYSIS + SULFUR)

- Elaboration of the polished coal sections.
- Medium reflectance of vitrinite test.
- Maceral composition test.
- Proximate analysis + sulfur tests.
- Preparation of reports.

STAGE 4: COAL CLASSIFICATION

- Classification of coals according to the ASTM D388-12 norm.
- Classification of coals according to the ISO 11760 norm.

STAGE 5: DETERMINATION OF PALEOENVIRONMENTS

- Determination of petrographic indices.
- Realization of ternary diagrams.
- Construction of block diagrams of environments.
- Paleoenvironmental interpretation.

STAGE 6: RELATIONSHIP OF PHYSICO-CHEMICAL PROPERTIES WITH DEPOSITACIONAL ENVIRONMENTS OF CARBONES

- Establish the change of physical chemical properties according to the depositional environment

STAGE 7: FINAL REPORT

- Group the obtained information.
- Conclusions of the research project.
- Presentation of the final report.

Figure 1. Methodology of work.

2. CHAPTER TWO: GEOLOGICAL AND STRATIGRAPHIC FRAMEWORK

2.1. LOCATION

The study area is located in Cundimarca and Boyacá provinces, in the eastern mountain range in Colombia. The geological structure where are found the coals is known as Checua-Lenguazaque syncline (Sutatausa, Tausa, Lenguazaque, Guachetá, Cucunubá, Samacá and Ráquira localities).

The approximate area of the zone is 1868 Km2, but the Guaduas Formation (Upper Cretaceous to Paleocene) outcrops have a smaller area (155.2 Km2). The companies don't have routes of the first order but there are different secondary ways to arrive to the different mines. From Bogota there is an approximate distance of 112 Km to the north, from Tunja 64 km to the west and from Ubate 30 Km to the east (Barrera Ponguta, 2016).

The location area is shown in the figure 2; nevertheless a detailed area with Guaduas Formation outcrops and the location of extracted samples will be show in the geological and stratigraphic framework. The study was realized in the western flank of the structure due to the presence of coals with higher quality in this zone in comparison with the eastern flank. 16 coal seams are economically exploitable for thickness, properties, purity and ease of access. Most of these coals are used in the coke industry (13) and the rest in the thermic industry (3). Different companies exploited this resource in this area as MINAS Y MINERALES S.A, S.I. CARBOCOQUE and S.I. MILPA S.A.

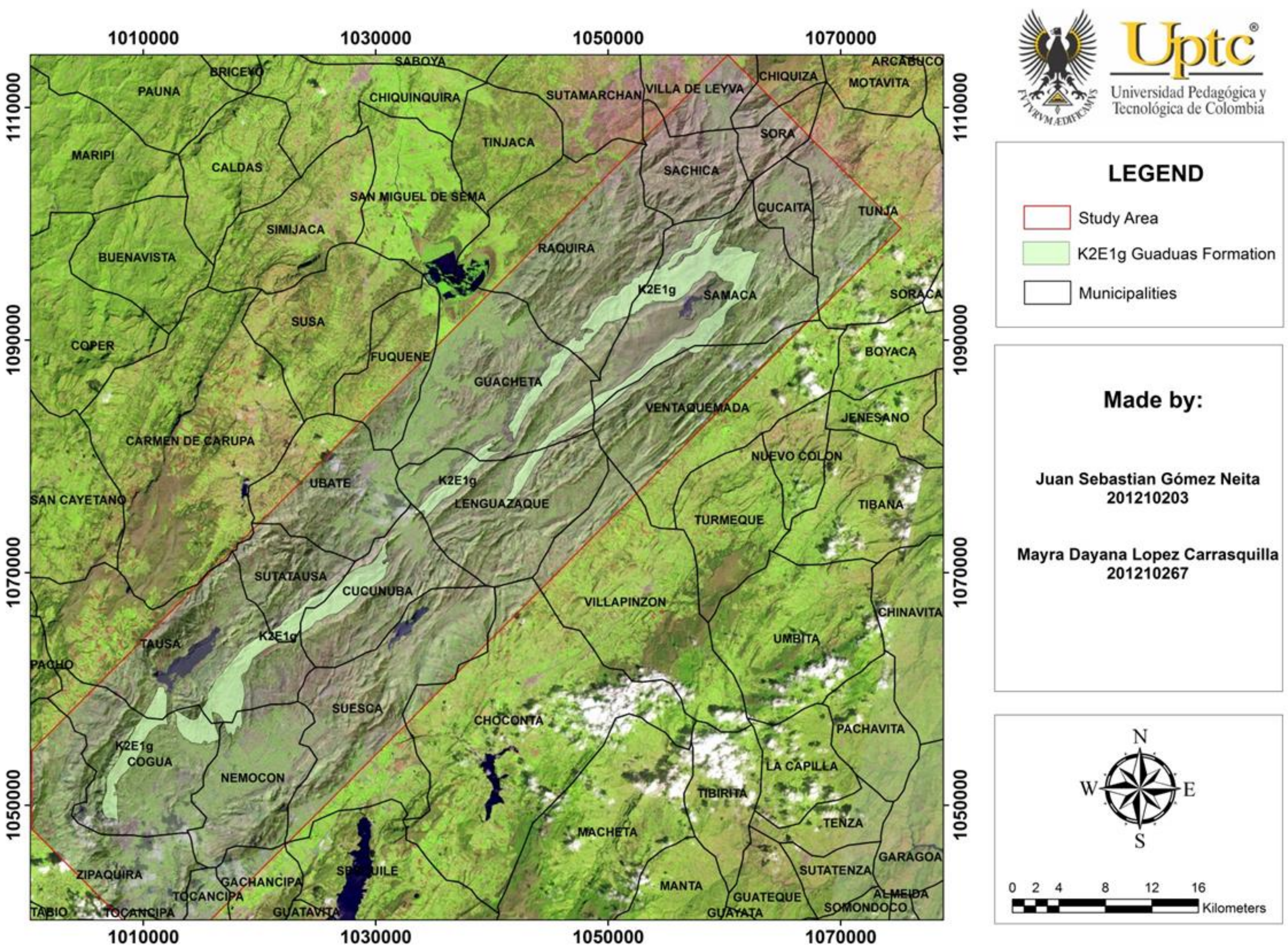

Figure 2. Location of the study area.

2.2. GEOLOGICAL SETTING

2.2.1. Regional geological framework.

In the eastern mountain range in Colombia, the cretaceous rocks represent a major cycle transgressive - regressive with minor important events of the same class (Cooper, et al., 1995) (Sarmiento-Rojas, Van Wess, & Cloe, 2006) (Amaya Medina, 2009), so above the Paleozoic sequence was deposited a thick Cretaceous sequence initially transgressive but later regressive in the upper Cretaceous to Paleocene (Etayo, Renzoni, & Barrero, 1969) (Fabre, 1985). The upper section of Guadalupe group and the Guaduas Formation (Maastrichtian to Paleocene) show the last regressive event of the Cretaceous sea and the continentalization of sediments from base to top in this unit (Sarmiento Pérez, 1991).

Hubach (1957) redefines the previous studies and he proposed the type section in the north of Bogotá next to the Guatavita locality but Laverde (1979) is the first to give an idea of the lithostatigraphic aspects and depositional models in this unit, the Guaduas Formation is preceded by the Guadalupe group with shallow sea facies and followed by the Cacho Formation with terrestrial facies of meandering rivers and flood plains.

2.2.2. Stratigraphy.

The stratigraphic succession is based in the description of Sarmiento Pérez (1991) in the Sutatausa section in Peñas de Boquerón; two stratigraphic units are shown, the upper part of Guadalupe group and the Guaduas Formation separated by a concordant contact.

2.2.2.1. Guadalupe group.

Sarmiento Pérez (1991) describes the upper section of this group in the way from Zipaquirá to Ubaté (Boquerón de Sutatausa) identifying two members, the firs one as an intercalation of mudstones and sandstones and the second one like an only sandy succession.

The lower member is characterized by fine-grained quartz sandstones with marks of Siphogenerinoides and phosphatic pellets, and mudstones with lenticular bedding to the top. The upper member consists in powerful sandstone beds with high bioturbation and a thin muddy intercalation with high content of organic matter (Sarmiento Pérez, 1991).

2.2.2.2. Guaduas Formation.

The contact between the Guadalupe group and the Guaduas Formation is net and it is detected by the morphologic changes in the study area. Sarmiento Pérez (1991) divided the Guaduas unit in nine segments according with vertical changes with lateral continuity.

2.2.2.2.1. Segment 1.

It is the section in contact with the Guadalupe group, it consists in claystones and mudstones in the first 60 m and, mudstones and fine-grained sandstones between 60 m and 129 m. The succession presents a light gray claystones with low content of organic matter; the mudstones present a high content of bivalves and lenticular bedding. The sandstones have wavy bedding and some rest of organic matter, they present flaser bedding and ripples. (Coastal lagoon and intertidal zone).

2.2.2.2.2. Segment 2.

This segment presents basal sandstones and it includes the firs sector of exploitable coals in the area. The sandstone presents an erosive contact with the mudstones and it has tangential lamination. The coals are characterized by rest of roots in the base and the mudstones present a high content of organic matter with macro vegetable rests. (Supratidal zone and lakes).

2.2.2.2.3. Segment 3.

This segment starts with a succession of sandstones (key bed 1); it presents an erosive base, cuneiform strata, intraclasts and FUS sequence. In the upper section the sandstone have mineral as tourmaline and zircon in low percent. (Rivers, flood plains and lakes).

2.2.2.2.4. Segment 4.

The major feature of this section is the quantity of exploitable coal seams and the high content of organic matter in the mudstones. The change with the next segment is defined by the transition from gray mudstones to red-blue mudstones; these mudstones show evidence of roots and sheets and accumulations of coals with lenticular bedding. (Close bog zone, open bog zone, Supratidal zone and estuarine channels).

2.2.2.2.5. Segment 5.

This section is characterized by the presence of varicolored mudstones without sedimentary structures evidenced and little content of organic matter. The segment presents siderite and gypsum in the contact with the carbon belts. (Lower plains).

2.2.2.2.6. Segment 6.

This segment presents the third zone of exploitable coals in the stratigraphic column but it presents more intercalations of clays. The sandstones have inclined bedding and FUS sequences. The mudstones present a high content of organic matter. The predominant structures are soft sedimentation structures (Convolute and slumps). (Meandering river channel and alluvial plain, intertidal and Supratidal zone, and bogs).

2.2.2.2.7. Segment 7.

It is characterized by the change of color with the previous segment. It has coals seam and it presents calcareous concretions and sideritic spherulites. The mudstones present a high content of organic matter and root marks. (Lower plains and intertidal zone).

2.2.2.2.8. Segment 8.

This segment is a sandy bank with a FUS succession and some beds of conglomerates with oriented intraclasts. Some of these sands were classified as lithic sandstones due to high content of metamorphic, igneous and sedimentary fragments. (Meandering channel).

2.2.2.2.9. Segment 9.

The section presents claystones with red and blue colors in intercalations with sandstones in the upper part. This segment is in contact with the Cacho Formation. The succession has a high content of pedogenic structures. (Meandering channels, alluvial plains).

Many authors have studied the area and they proposed different divisions for the Guaduas formation (table 1) (Nigrinis (1975), Laverde (1979), Sarmiento (1991) and Barrera (2016)). For the elaboration of the geological map (figure 3) was use the Laverde and Barrera divisions dividing the Guaduas formation in three members (lower, medium and upper).

Table 1.
Divisions of the Guaduas Formation, modified from Barrera Ponguta (2016).

	Nigrinis (1975)	**Laverde (1979)**	**Sarmiento (1991)**	**UPTC project (2016-2017)**
GUADUAS FORMATION	KTg5	Upper Guaduas	Ktg s- 9	K2E1g3
	KTg4		Ktg s- 8	
			Ktg s- 7	K2E1g2
	KTg3	Medium Guaduas	Ktg s- 6	
			Ktg s- 5	
	KTg2		Ktg s- 4	
			Ktg s- 3	
	KTg1	Lower Guaduas	Ktg s- 2	K2E1g1
			Ktg s- 1	

Three stratigraphic sections were modified from Sarmiento (1992) and Ingeominas –Carbocol- Colciencias (1992) according with the obtained data from different companies to put the coal seams in the correct level. This interpretation was realized using the vitrinite reflectance, structural studies and well data. It is very important the position of coals in the sedimentary succession to interpret the associated depositional environment and make a correlation with the given environments from organic petrography. The Sutatausa´s column (Figure 4) presents 16 seams, here 13 of these coals were sampled to realize the petrographic studies; the Guachetá section (Figure 5) with its representative column has 19 exploitable coal seams of which 17 were sampled in the project. The Samaca´s column presents 18 coal seams and here 14 of these were sampled how is shown in the figure 6, however make an exactly correlation is complicated due the intensive tectonic events in the north of the syncline.

2.2.3. Geological structures.

The regional structure is the Checua-Lenguazaque syncline with a preferential orientation SW-NE, it is an asymmetric and inverted structure due the Cucunubá fault in the north. In the south the structure is covered by quaternary deposits (Barrera Ponguta, 2016) how is shown in the figure 3.

The western flank presents a general strike of N40E and dips of 45° to 70° SE (UPME, 2012) being more inclined in the north. In the core are the Bogota and Regadera Formations and its flanks the Guadalupe group, and the Guaduas and Cacho Formations.

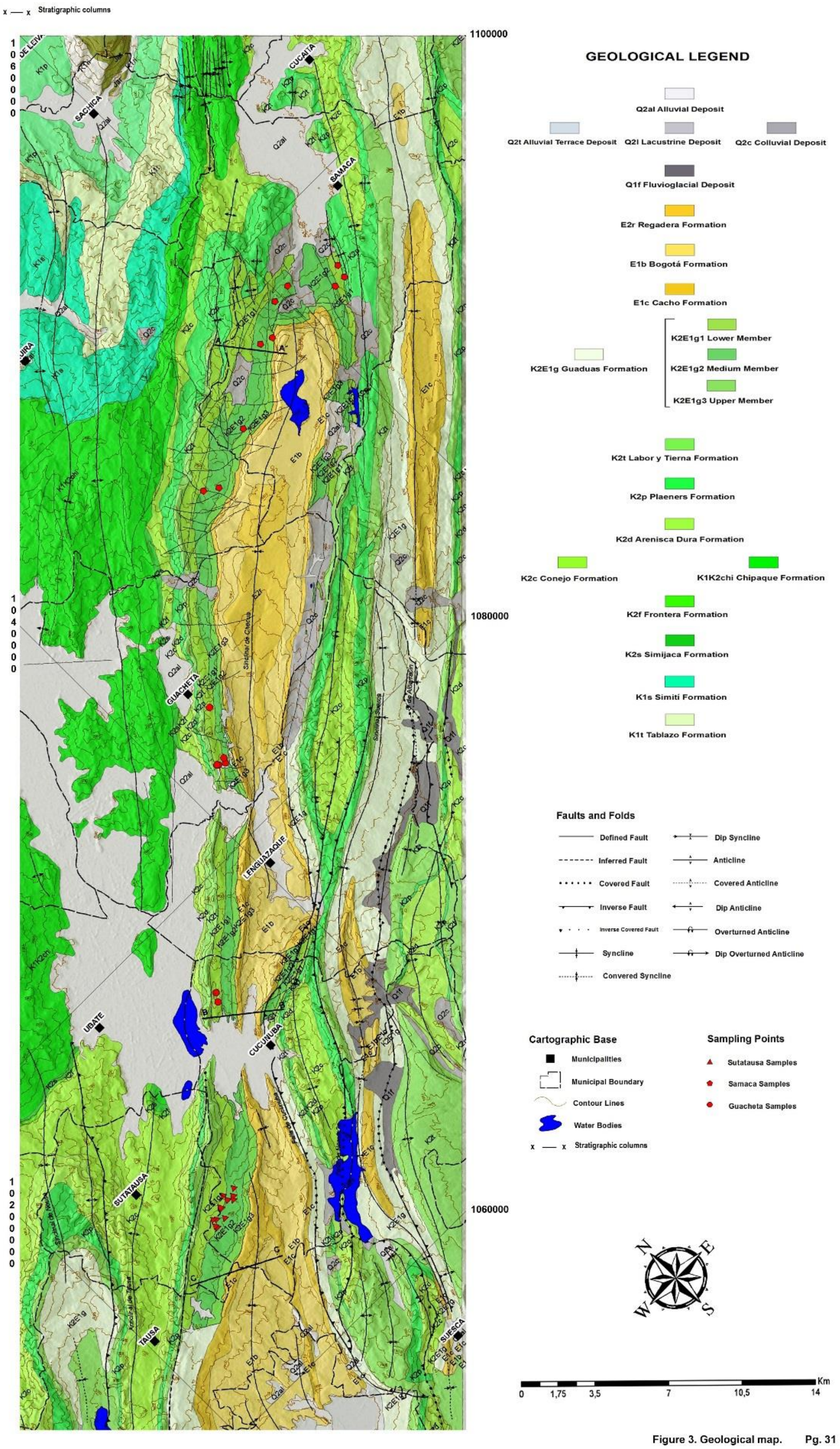

Figure 3. Geological map (Modified from Barrera Ponguta (2016), Sarmiento Pérez (1991) and Duarte B. & Parra C. (2012)),

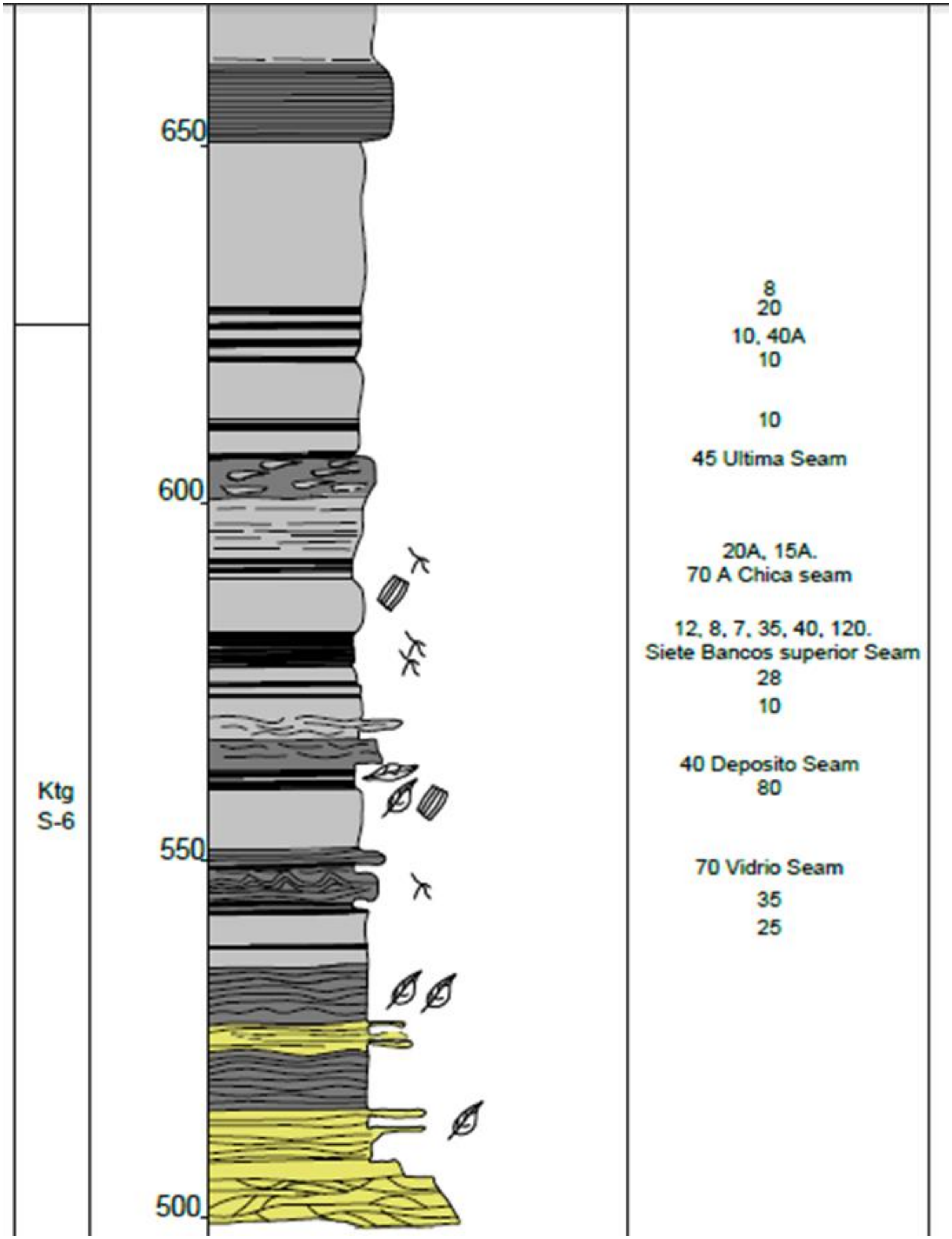

Figure 4. Sutatausa´s stratigraphic column (Modified from Sarmiento Pérez (1991) and INGEOMINAS, (1992)).

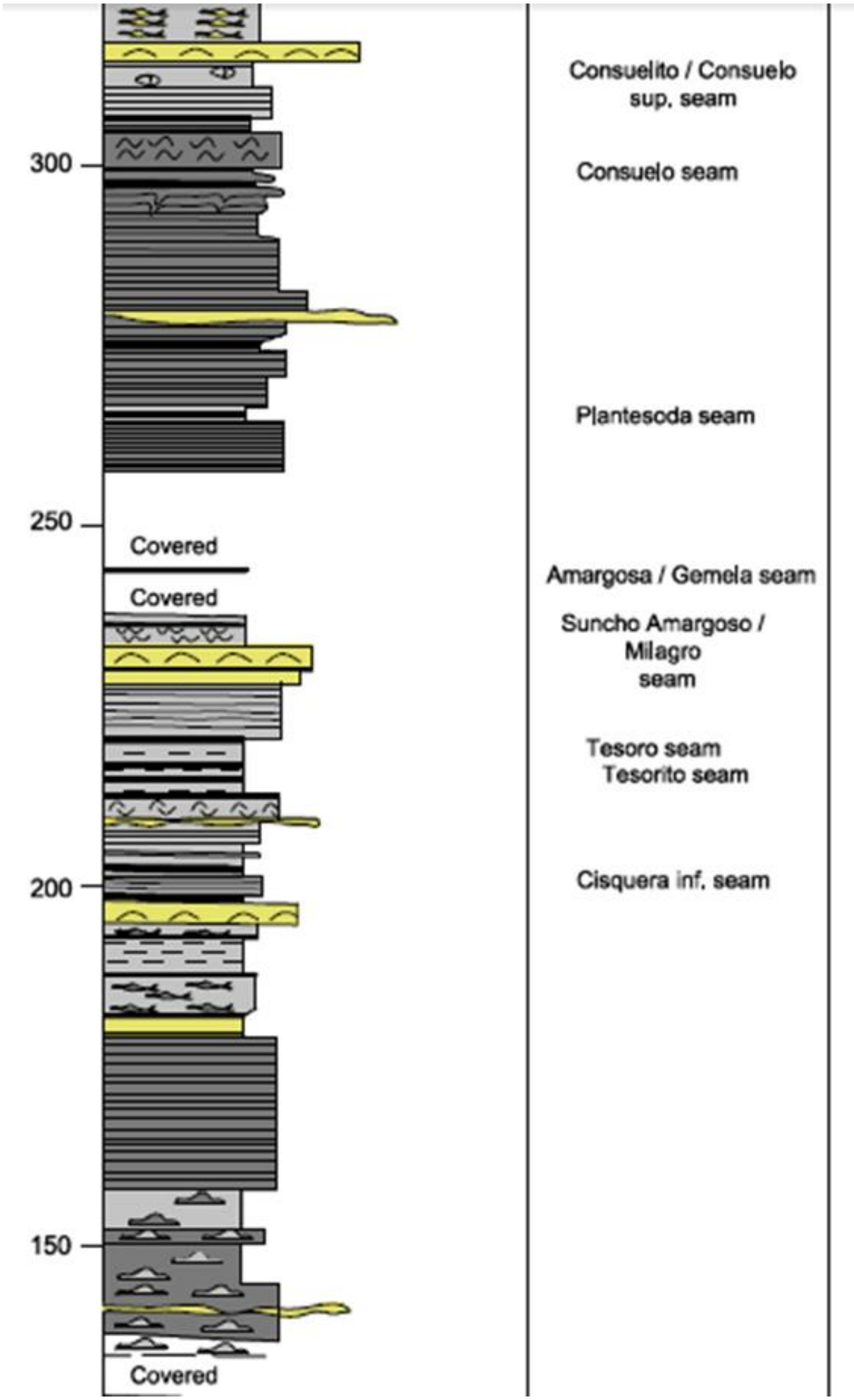

Figure 5. Guachetá´s stratigraphic column (Modified from INGEOMINAS (1992)).

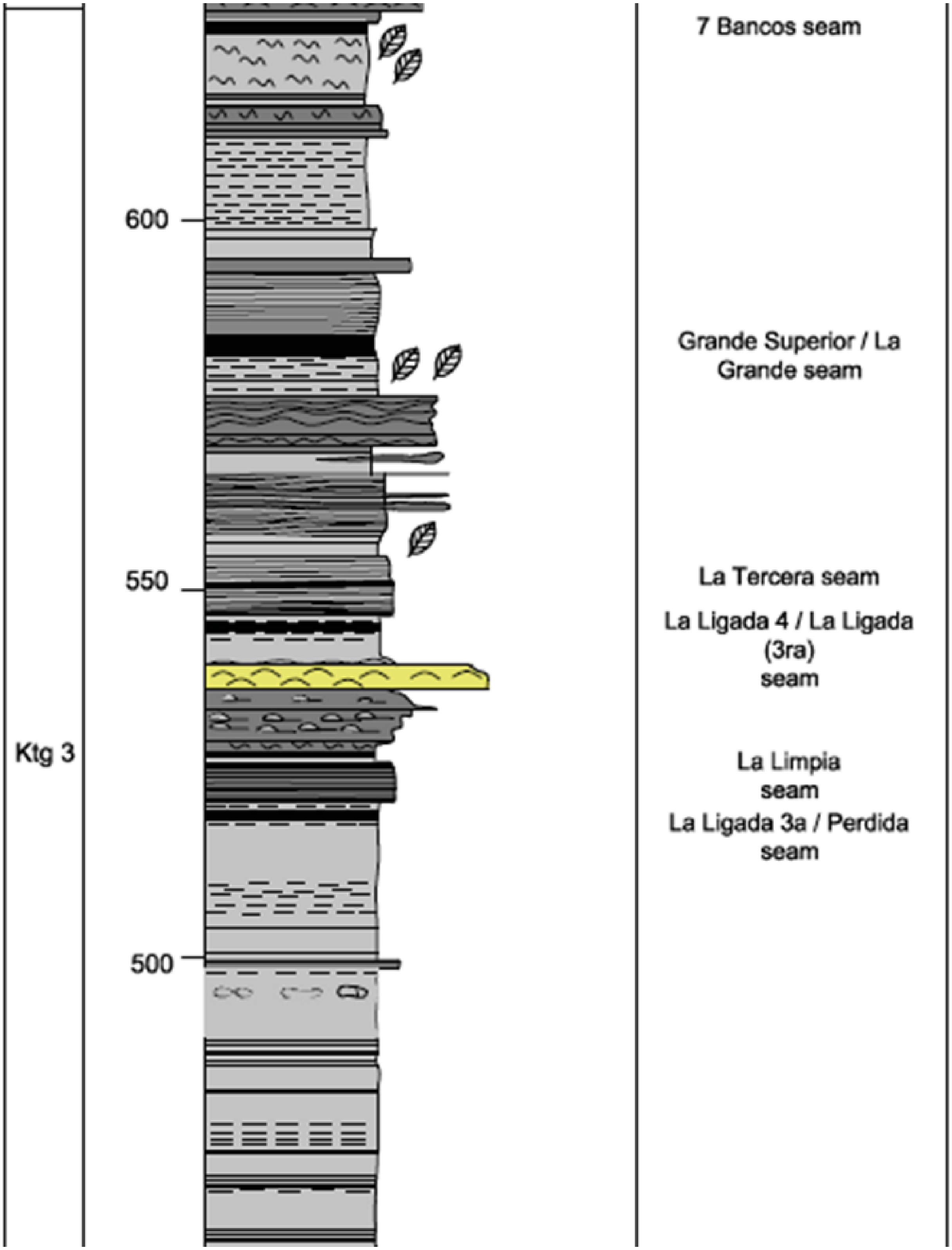

Figure 6. Samacá´s stratigraphic column (Modified from INGEOMINAS (1992)).

3. CHAPTER THREE: COAL PETROGRAPHY

The organic petrography is a recent technique used to determine the rank of the coals like an alternative to the proximate analysis. Through this science is possible know the maturation of the coals and their composition with the purpose to predict the behavior in the different industrial processes like the production of energy and coke. For this study the coal samples were analyzed with two parameters, random reflectance of vitrinite and maceral composition, the first one used to determine the rank of coalification and the second one to determine the organic constituents and their origin.

3.1. REFLECTANCE OF VITRINITE

This parameter is an effective tool to determine the grade of coalification of coal gets it with the increase of the temperature and pressure like function of the paleogeothermal gradient and the time in the sedimentary basin (Barrera Ponguta, 2016). The random reflectance of vitrinite (Ro) allowed the determination of the maximum obtained temperature (Tpeak) in the burial history according with the equation 1 proposed by Barker & Pawlewicz (1994).

$$\mathrm{Tpeak} = \frac{\mathrm{Ln(Rom)} + 1.68}{0.0124}$$

Tpeak: Maximum temperature
Rom: Random mean reflectance of vitrinite

Equation 1. Barker and Palewlewicz equation to determine the peak temperature in a basin without hydrothermal processes.

The maturity of coals increase with depth how is shown in the table 2, 3 and 4, thus the results indicate that the sedimentary basin had a different paleogeothermal gradient in its three sections along the Checua-Lenguazaque syncline, 52°C/Km for Sutatausa, 82°C/Km for Guachetá and 100°C/Km for Samacá with maximum temperatures between 105°C and 170°C according with the stratigraphic position and the lithostatic charge of each coal along the geologic history (Barrera Ponguta, 2016).

Table 2.

Random mean reflectance of vitrinite and peak temperature, Sutatausa block.

BLOCK	CODE	SEAM	Rom	Tpeak	GRADIENT
SUTATAUSA	S14	7 BANCOS SUPERIOR	0,69	105	52°c/Km
SUTATAUSA	S13	DEPOSITO	0,75	112	
SUTATAUSA	S11	CISCUDA	0,79	117	
SUTATAUSA	S10	CISCUDA	0,81	118	
SUTATAUSA	S09	CHICA 3	0,82	119	
SUTATAUSA	S12	QUINTAS	0,85	122	
SUTATAUSA	S17	GRANDE 2	0,88	125	
SUTATAUSA	S16	CHICA 2	0,89	126	
SUTATAUSA	S15	7 BANCOS INFERIOR	0,88	125	
SUTATAUSA	S07	GEMELA SUPERIOR	0,91	128	
SUTATAUSA	S05	GEMELA SUPERIOR	0,92	129	
SUTATAUSA	S06	GEMELA INFERIOR	0,94	130	
SUTATAUSA	S04	GEMELA INFERIOR	0,95	132	
SUTATAUSA	S01	LA GRANDE 1	0,93	130	
SUTATAUSA	S02	LA GRANDE 1	0,94	130	
SUTATAUSA	S03	CHICA 1	0,98	134	
SUTATAUSA	S08	VETA PRIMERA	0,95	131	

Table 3.

Random mean reflectance of vitrinite and peak temperature, Guachetá block.

BLOCK	CODE	SEAM	Rom	Tpeak	GRADIENT
GUACHETÁ	G13	7 BANCOS	1,01	136	82°c/Km
GUACHETÁ	G01	SUNCHO CISQUERA	1,03	138	
GUACHETÁ	G02	CISQUERA NIVEL 80	1,06	140	
GUACHETÁ	G04	CISQUERA NIVEL 180	1,07	141	
GUACHETÁ	G18	CISQUERA (NIVEL300)	1,08	142	
GUACHETÁ	G16	VETA GRANDE	0,96	132	
GUACHETÁ	G20	MANTO 2	0,94	131	
GUACHETÁ	G15	BOCATOMA NIVEL 220	1,39	162	
GUACHETÁ	G12	PIEDRO	1,25	154	
GUACHETÁ	G08	BOLAS	1,29	156	
GUACHETÁ	G11	CONSUELO SUPERIOR	1,38	161	
GUACHETÁ	G10	CONSUELO	1,48	167	
GUACHETÁ	G14	PLANTA DE SODA	1,40	162	

GUACHETÁ	G07	GEMELAS	1,44	165
GUACHETÁ	G03	CUARTAS	1,03	137
GUACHETÁ	G09	MILAGROS	1,45	166
GUACHETÁ	G06	TESORO	1,52	169
GUACHETÁ	G19	TESORO	1,05	139
GUACHETÁ	G05	TESORITO	1,53	170
GUACHETÁ	G17	TESORITO	1,01	136
GUACHETÁ	G21	CISQUERA INFERIOR	1,60	173

Table 4.
Random mean reflectance of vitrinite and peak temperature, Samacá block.

BLOCK	CODE	SEAM	Rom	Tpeak	GRADIENT
SAMACA	SM23	SIETE BANCOS	0,93	130	
SAMACA	SM04	LA GRANDE	0,93	129	
SAMACA	SM02	TERCERA INFERIOR	0,85	123	
SAMACA	SM01	TERCERA SUPERIOR	0,89	126	
SAMACA	SM03	TER. (LA LIGADA)	0,84	121	
SAMACA	SM26	LIGADA	0,91	128	
SAMACA	SM11	PERDIDA SUPERIOR	1,27	155	
SAMACA	SM12	PERDIDA INFERIOR	1,29	156	
SAMACA	SM16	BOCATOMA	1,33	158	
SAMACA	SM05	BOCATOMA	1,41	163	
SAMACA	SM06	RUBI	1,29	156	
SAMACA	SM17	RUBI SUPERIOR	1,41	163	
SAMACA	SM18	RUBI INFERIOR	1,45	165	
SAMACA	SM15	PIEDRO SUPERIOR	1,44	165	100°c/Km
SAMACA	SM07	PIEDRO INTERMEDIO	1,30	157	
SAMACA	SM14	PIEDRO MEDIO	1,41	163	
SAMACA	SM08	PIEDRO INFERIOR	1,22	152	
SAMACA	SM13	PIEDRO INFERIOR	1,32	158	
SAMACA	SM09	CONSUELO SUPERIOR	1,34	159	
SAMACA	SM10	CONSUELO INTERMEDIO	1,31	157	
SAMACA	SM19	CONSUELO	1,41	163	
SAMACA	SM24	GEMELA SUPERIOR	1,24	153	
SAMACA	SM25	GEMELA INFERIOR	1,23	152	
SAMACA	SM21	TESORO	1,25	153	
SAMACA	SM20	TESORITO	1,27	154	
SAMACA	SM22	CISCUDA (CISQUERA)	1,33	159	

3.2. MACERAL COMPOSITION

This analysis helps to define the organic constituents of coal which allow determine the coalified remains of tissues or substances derived from plants existing in the peat formation although it is not always is possible the recognition the precursor material of each maceral, so the quality and composition of coal depends the climatic and ecological controls, plant community, burial history and condition of the environment when the organic matter was deposited, that later it will have changes in its structural, physical and chemical properties during the metamorphism process from peat to meta-anthracite (Suarez Ruiz & Crelling, 2008). The maceral reading distinguishes three groups (Figure 7), liptinite, inertinite and vitrinite/huminite; with their respective sub-groups and macerals, each one formed as result of different biochemical and geochemical processes.

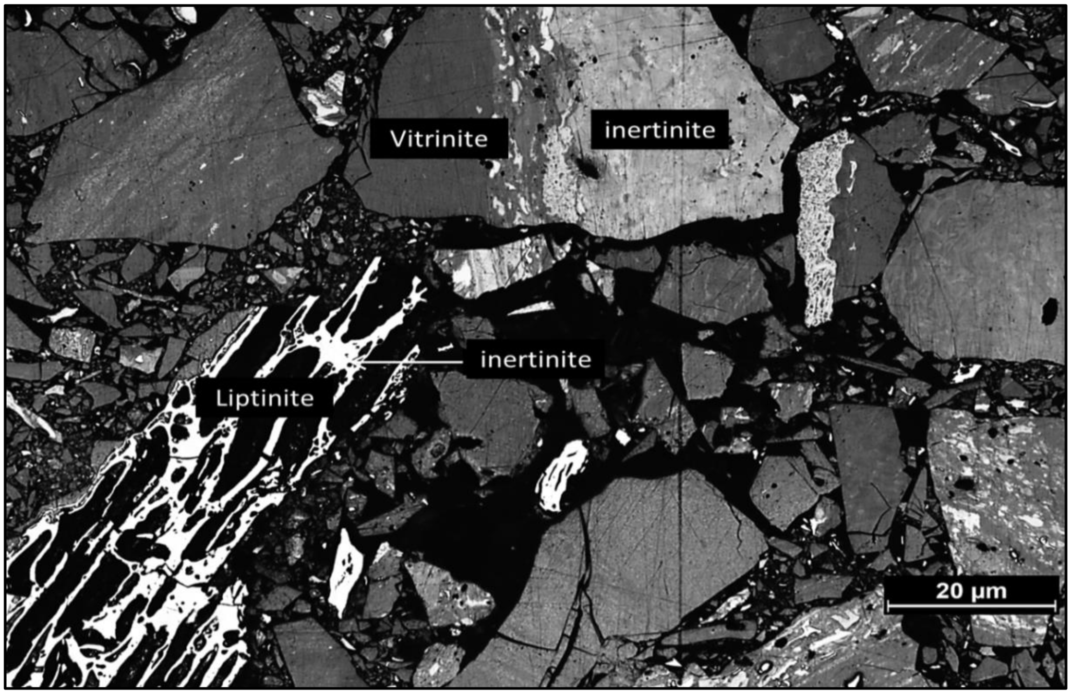

Figure 7. Micro-photo of coal sample (Guachetá block), with the maceral groups, vitrinite, liptinite and inertinite.

The identification of the macerals depends of the reflectance (Color), forms and degree of destruction and preservation of the organic material (Cellular structure, gelification and morphological features (Suarez Ruiz & Crelling, 2008). The described macerals in the study are shown in the table 5 according with the features and their predominance in the composition of the Colombian coals; for this case there were no coals of low rank for which the vitrinite/huminite group was describe only with the vitrinite macerals.

Table 5.
Table of each maceral group with their subgroups, macerals and respective origin processes modified (Suarez Ruiz & Crelling, 2008).

<table>
<tr><th>MACERAL GROUP</th><th>SUB-GROUP</th><th>MACERAL</th><th>ORIGIN</th></tr>
<tr><td rowspan="10">Liptinite</td><td rowspan="10">-</td><td>Sporinite</td><td>From pollen and spores</td></tr>
<tr><td>Cutinite</td><td>From cuticles and leaves</td></tr>
<tr><td>Resinite</td><td>Diverse origins. Resins, waxes</td></tr>
<tr><td>Alginite</td><td>Algal or bacterial</td></tr>
<tr><td>Suberinite</td><td>From subaereous tissues</td></tr>
<tr><td>Chloro-phyllinite</td><td>From Chlorophyllic pigments</td></tr>
<tr><td>liptodetrinite</td><td>Fragments from other liptinite macerals</td></tr>
<tr><td>Fluorinite</td><td>From vegetable oils</td></tr>
<tr><td>Bituminite</td><td>Degradation product from algae, bacterial, zooplankton</td></tr>
<tr><td>Exudatinite</td><td>From hydrogenated substances and liptinite macerals</td></tr>
<tr><td rowspan="7">Inertinite</td><td rowspan="7">-</td><td>Fusinite</td><td>From ligno-cellulosic cell walls</td></tr>
<tr><td>Semifusinite</td><td>From parenchymatous and xylem tissues od steams, herbaceous plants and leaves</td></tr>
<tr><td>Funginite</td><td>From fungal spores and tissues, sclerotia, mycelia</td></tr>
<tr><td>Secretinite</td><td>No totally clear, oxidation product of resins, humic gels</td></tr>
<tr><td>Macrinite</td><td>From alteration of humic substances, metabolic product of fungi and bacteria, from coprolites, etc.</td></tr>
<tr><td>Micrinite</td><td>Coalification product, residues of formed lipoid substances, strong fragmentation of other inertinites</td></tr>
<tr><td>inertodetrinite</td><td>From phytogenetic material subjected to fusinization</td></tr>
<tr><td rowspan="6">Vitrinite</td><td rowspan="2">Telo-vitrinite</td><td>Telinite</td><td rowspan="2">From parenchymatous and woody tissues composed of cellulose and lignin</td></tr>
<tr><td>Collotelinite</td></tr>
<tr><td rowspan="2">Detro-vitrinite</td><td>Vitrodetrinite</td><td rowspan="2">From strong decay of parenchymatous and woody tissues of steam and leaves originally composed of cellulose and lignin</td></tr>
<tr><td>Collodetrinite</td></tr>
<tr><td rowspan="2">Gelo-vitrinite</td><td>Corpogelinite</td><td rowspan="2">From jelling humic solutions and not corresponding to specific plant tissues. From contents of plant cells or humic fluids</td></tr>
<tr><td>Gelinite</td></tr>
</table>

3.2.1. Liptinite group.

The macerals of this group include all distinct part of plants such as spores, cuticles, products of degradation, resins, oils, secondary products, etc; formed during the process of coalification. Chemically these macerals have high contents of hydrogen and aliphatic (Suarez Ruiz & Crelling, 2008). In the polished probe they are recognized by a dark color and to display fluorescence with wavelength radiation as is shown in the figure 8.

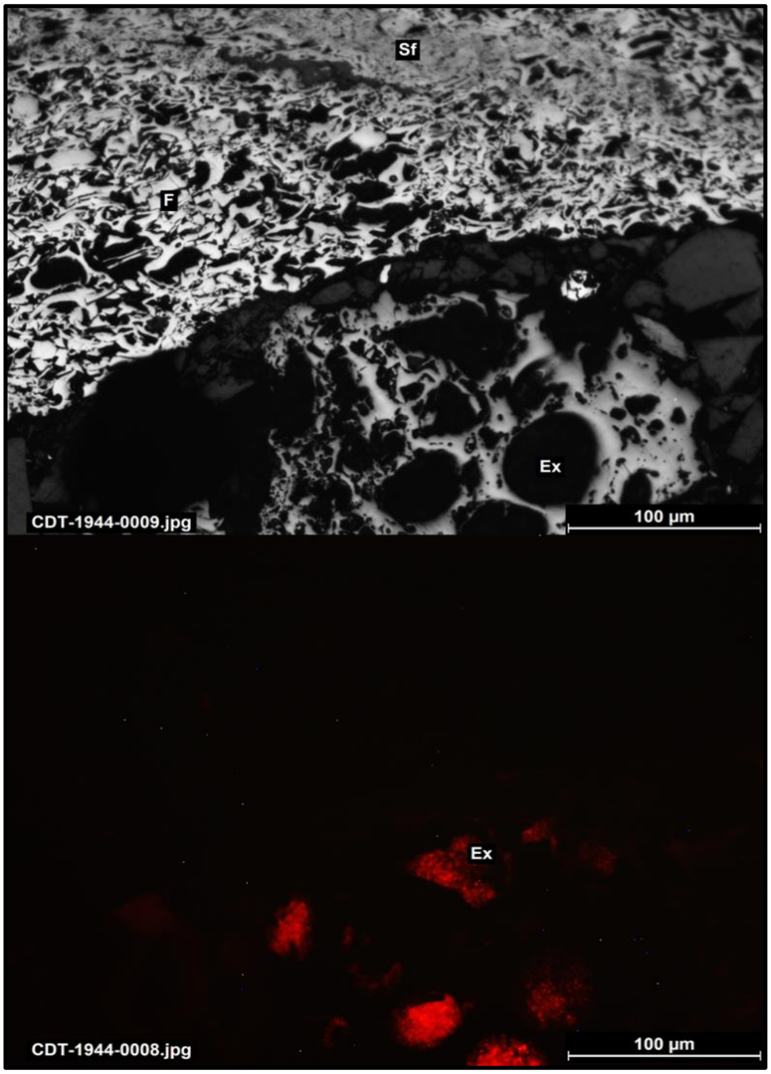

Figure 8. Fluorescence of Exudatinite (Ex) (Liptinite) fills a cell hole of fusinite (Micro-photo of a coal sample of the Sutatausa block).

For coals of this study it is the maceral group with the lower percentage, due to the major components tend to change along the coalification as result de increase of rank with the chemical transformations.

3.2.2. Inertinite group.

This group is characterized to present the highest reflectance as is shown in the figure 9. The material that origin this maceral group was altered and degraded due the oxidation, redox, chemical and biochemical action and transformation of hydrogenated macerals in the peat stage, chemically the inertinite group present an aromatic character, it has the highest carbon and lowest oxygen and hydrogen contents (Suarez Ruiz & Crelling, 2008).

The type of maceral of this group depends of the degree the preservation of the vegetable structures. The name inertinite refers to the behavior in the combustion; however some part of the semifusinite is reactive. The presence of this group in coals allowed the production of a coke with good strength and stability.

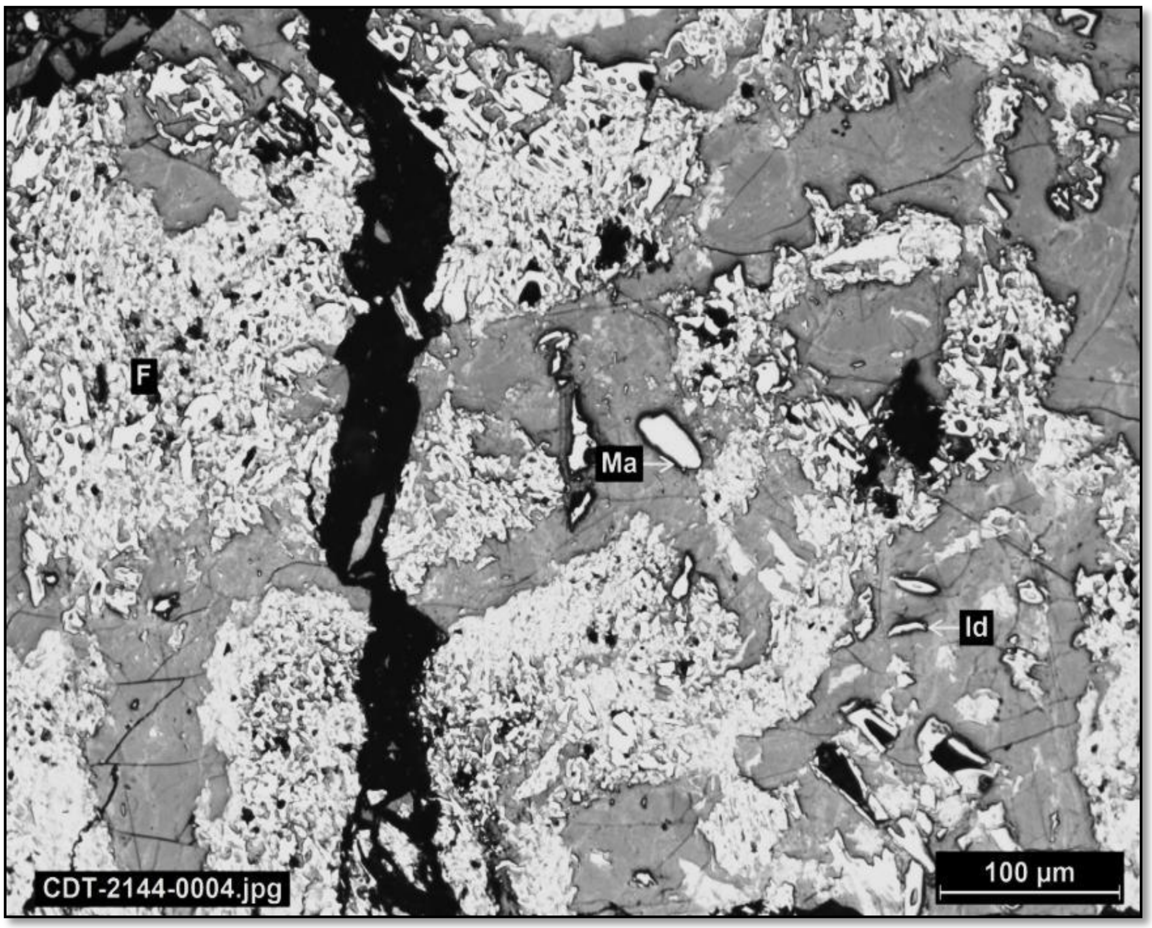

Figure 9. Macerals of the inertinite group. Fusinite (F), macrinite (Ma) and inertodetrinite (Id) (Micro-photo of a coal sample of the Samacá block).

3.2.3. Vitrinite group.

The macerals of this group are originated mainly from cellulose and lignin but they have other components like tannins, colloidal humic gels, proteins and lipid substances (Suarez Ruiz & Crelling, 2008). The chemical structure in high rank coals (Bituminous) consist in aromatic compounds but this one change along the coalification process with the humification, gelification, and vitrinization (Suarez Ruiz & Crelling, 2008). The macerals of the vitrinite group are recognized in the reflected light for their color, medium grey, being in the medium the liptinites (Darker) and inertinites (Lighter) as is showed in the figure 10, likewise "Chemically the huminite and vitrinite groups have relatively high oxygen contents compared with the other two maceral groups" (Suarez Ruiz & Crelling, 2008, pág. 28).

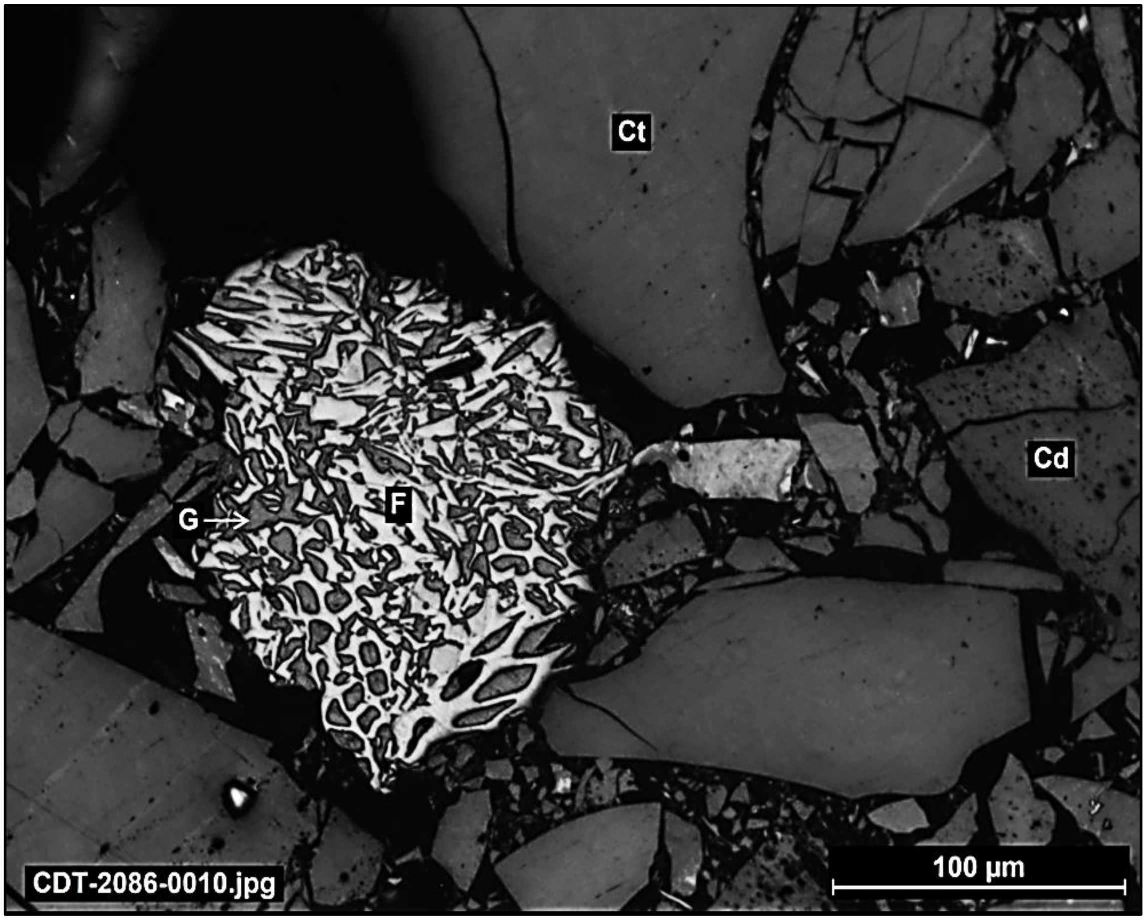

Figure 10. Macerals of the vitrinite group. Collotelinite (Ct), Collodetrinite (Cd) and gelinite (G) (Micro-photo of a coal sample of the Samacá block).

High values of vitrinite in a coal indicate that the peatbog was covered by water inhibiting the oxidation of the organic matter (Guatame & Sarmiento, 2004) thus the discrimination between the macerals of this group allowed to know the degree of conservation of tissues, chemical and physical processes, and kind of organic matter which originated the coal (Guatame & Sarmiento, 2004).

3.2.4. Mineral matter.

The mineral matter is an important constituent of coal due to it will represent the ash content after combustion. The major components for these coals are clays, iron oxides, pyrite and quartz; however a chemical analysis of ash is necessary to give an exact composition.

The inorganic constituents represent an inert component, so this percentage will not react during combustion and it will be to the coke frame with the inertinites. In the figure 11 are shown the most common minerals in the study samples. The coals with high values of mineral matter have to be manipulated for the reduction of this one using the washability technique.

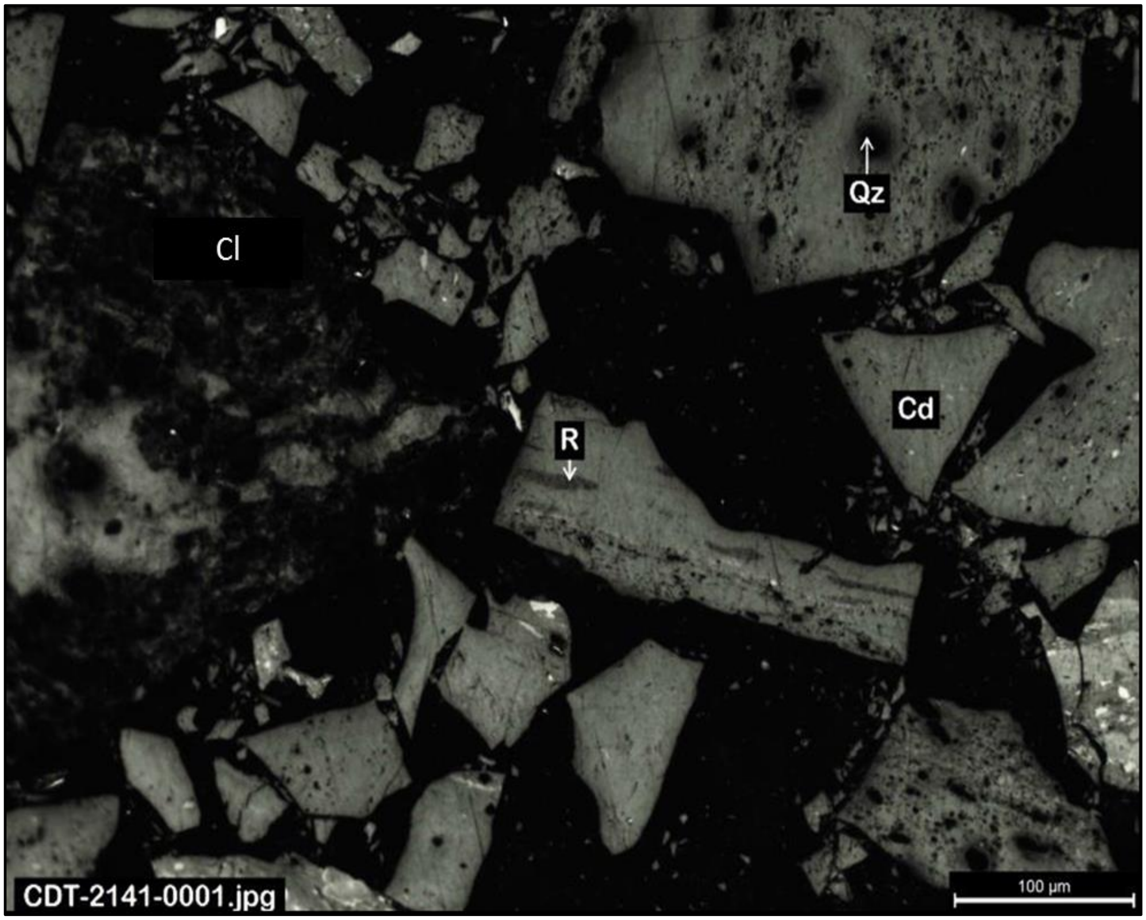

Figure 11. Mineral matter. Clay minerals (C), quartz (Qz) (Micro-photo of a coal sample of the Samacá block).

The maceral composition in the three sections presents a preferential disposition to vitric coals. The vitrinite content varied between 51.40% - 87.00%; with a fusic tendency related with oxic processes before deposition (content of inertinite between 5.40% - 43.80%). Macerals of the Liptinite group and mineral matter were in minor proportion in comparison with the other maceral groups, 0.20% to 14.00 % and 0.40% - 18.00% respectively. The results of the three sections are presented in the figures 12, 13 and 14.

A high content of macerals of the vitrinite group in a coal is a good indicator of preservation of the organic matter against degrading and oxic processes as product of forest fires and floods, so this increase of vitrinite in the maceral reading evidences the inundation of peatbog during the deposition (Nowak & Nowak, 1999).

The Bolas seam in the Guachetá section is the coal with higher content of inertinite; possibly to be on a fluvial event in the stratigraphic column presenting a high content of ash too (10.74%); in the same way the FSI test shows a value of 5.5 the lower beside Planta de Soda seam, which in the moment of coke production generating a coke with more resistance.

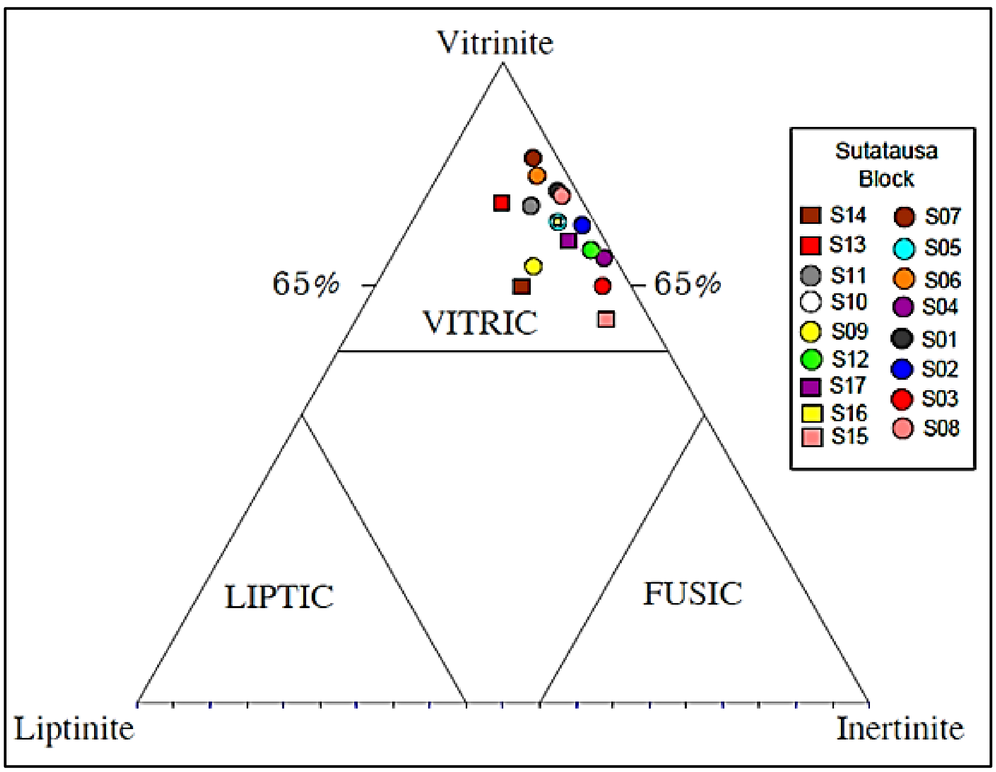

Figure 12. Maceral groups in the Sutatausa section.

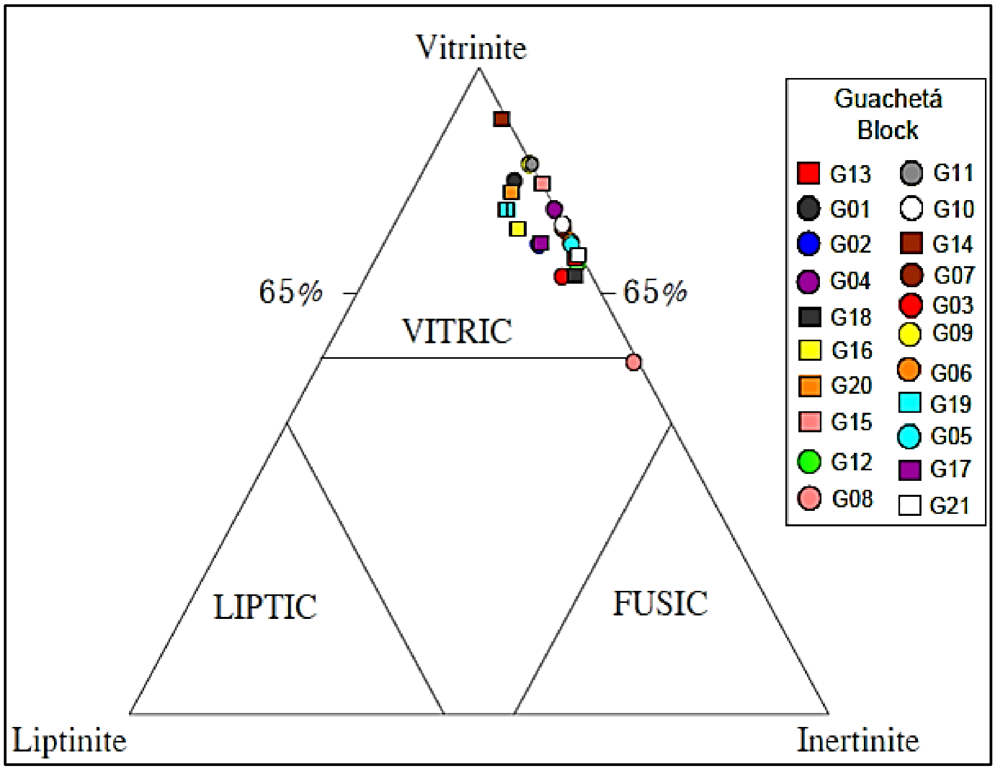

Figure 13. Maceral groups in the Guachetá section.

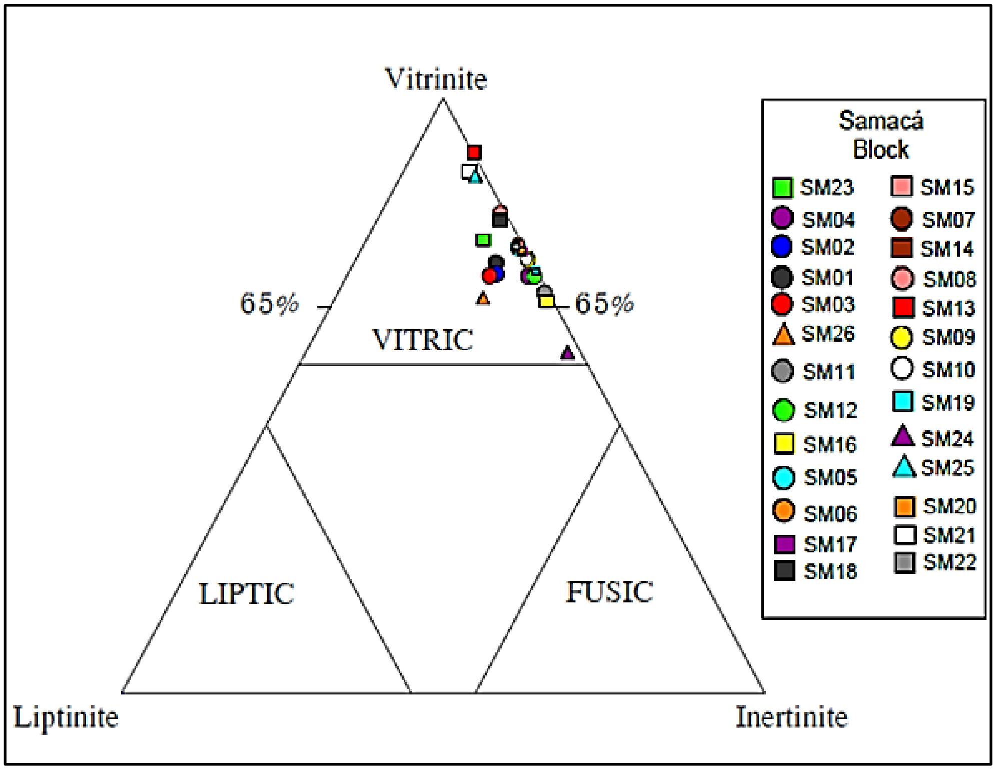

Figure 14. Maceral groups in the Samacá section.

3.2.5. Maceral reading.

This test allows the determination of the organic constituents of coal; these samples are enriched in terrestrial materials and they have good proportions of reactive / inert how is show in the tables 6, 7 and 8, so they are humic coals according with the Diessel diagram.

The maceral reading showed that coals from this area are enriched in macerals of the vitrinite group which correspond with the results of Guatame & Sarmiento (2004) and Mejia Umaña, Convers Gomez, & Gonzales Casallas (2006) in their studies for Guaduas Formation in the provinces of Cundinamarca and Boyacá, however the samples present a fusic trend due the degradation processes in the peat stage. The discrimination between the different macerals helps to determine de petrographic indexes and to position the coals samples in diagrams to interpret the depositional environments; likewise some ternary diagrams complement this information.

Three maceral groups were define with different proportions, the vitrinite range varied between (51.40% - 87.00%), followed by the inertinite group (5.40% - 43.80%), liptinite (0.20% - 14.0%), and mineral matter (0.40% - 18.00%); for the Sutatausa block the percentages were between 57.40% - 80.20% ; 1.80% - 14.00%; 9.60% - 32.40% and 0.40% - 17.40% respectively, for Guachetá between 51.40% - 83.20% ; 0,20% - 6.80%; 5.40% - 43.80% and 0.80% - 18.00%, and for Samacá 55.80% - 87.00% ; 0.20% - 9.60%; 8.20% - 40.20% and 1.00% - 12.00%.

Table 6.
Maceral composition of coals (Sutatausa block).

BK	CODE	V	L	I	MM	VITRINITE						LIPTINITE						INERTINITE						MINERAL MATTER					REAC-TIVES	INERTS
						T	CT	VD	CD	CG	G	R	CU	SP	LD	EX	AL	FU	SF	MA	MI	FG	ID	OP	IP	CM	FM	QZ		
SUT.	S14	61,0	14,0	18,8	6,2	0,2	20,4	1,0	39,0	0,2	0,2	2,0	6,2	0,0	5,8	0,0	0,0	1,6	8,6	1,2	5,8	0,0	1,6	0,6	0,2	4,4	0,0	1,0	77,9	22,1
SUT.	S13	66,0	9,8	9,6	14,6	0,6	31,0	1,0	32,4	0,6	0,4	2,2	4,8	0,0	2,8	0,0	0,0	1,0	4,4	0,2	2,0	0,2	1,8	0,4	1,2	11,8	0,0	1,2	77,3	22,7
SUT.	S11	70,6	6,6	13,8	9,0	4,4	26,0	0,0	39,6	0,0	0,6	2,2	3,6	0,2	0,2	0,4	0,0	0,8	6,4	0,6	4,4	0,0	1,6	0,4	0,0	7,6	0,0	1,0	79,3	20,7
SUT.	S10	68,4	5,2	18,0	8,4	0,2	28,4	0,0	39,6	0,2	0,0	2,4	1,6	0,0	0,2	1,0	0,0	2,4	10,2	0,2	3,4	0,2	1,6	0,6	0,2	6,6	0,0	1,0	77,0	23,0
SUT.	S09	66,2	11,8	18,8	3,2	2,2	29,2	0,4	30,2	0,6	3,6	3,2	6,2	0,2	2,0	0,2	0,0	1,8	6,6	1,6	7,2	0,4	1,2	0,2	0,0	2,4	0,2	0,4	80,2	19,8
SUT.	S12	69,2	3,0	25,6	2,2	0,2	27,8	0,0	41,2	0,0	0,0	2,0	0,4	0,0	0,2	0,4	0,0	2,2	12,2	1,4	5,8	0,2	3,8	0,0	0,0	1,8	0,2	0,2	76,3	23,7
SUT.	S17	60,2	4,4	18,0	17,4	0,8	31,8	1,2	26,4	0,0	0,0	0,8	2,2	0,0	1,2	0,2	0,0	1,8	5,2	0,4	7,4	0,4	2,8	1,6	0,4	5,6	8,0	1,8	66,3	33,7
SUT.	S16	74,8	5,0	19,8	0,4	0,2	30,4	0,0	44,2	0,0	0,0	2,4	1,6	0,0	0,6	0,4	0,0	1,2	7,8	1,2	4,6	0,4	4,6	0,0	0,0	0,0	0,2	0,2	82,4	17,6
SUT.	S15	57,4	6,0	32,4	4,2	0,2	20,2	0,0	36,4	0,4	0,2	1,4	1,8	0,0	2,6	0,2	0,0	2,8	8,6	1,6	13,4	0,0	6,0	0,0	0,0	4,0	0,0	0,2	66,3	33,7
SUT.	S07	80,2	3,2	11,0	5,6	0,6	48,8	0,4	30,4	0,0	0,0	1,0	1,2	0,0	0,0	1,0	0,0	2,4	3,0	0,0	2,8	0,0	2,8	0,0	0,0	4,4	0,4	0,8	84,4	15,6
SUT.	S05	72,6	4,8	19,6	3,0	1,0	43,6	0,0	28,0	0,0	0,0	1,4	2,0	0,0	0,8	0,6	0,0	2,4	3,0	0,6	9,8	0,0	3,8	0,0	0,0	1,2	0,0	1,8	78,4	21,6
SUT.	S06	78,4	4,0	12,6	5,0	1,2	47,0	0,0	30,2	0,0	0,0	1,6	1,6	0,0	0,2	0,6	0,0	0,6	4,4	0,8	3,8	0,0	3,0	0,0	0,0	3,8	0,0	1,2	83,9	16,1
SUT.	S04	65,6	2,4	27,8	4,2	1,4	33,6	0,2	30,0	0,2	0,2	0,6	0,2	0,2	0,4	1,0	0,0	1,2	12,0	0,6	8,6	0,0	5,4	0,2	0,0	1,8	0,0	2,2	72,0	28,0
SUT.	S01	74,6	3,2	16,0	6,2	1,8	49,2	0,0	23,4	0,2	0,0	1,8	0,4	0,0	0,0	1,0	0,0	1,4	6,2	0,4	6,4	0,0	1,6	0,0	0,0	4,2	0,2	1,8	79,9	20,1
SUT.	S02	67,4	1,8	21,8	9,0	1,4	43,0	0,0	23,0	0,0	0,0	0,2	0,4	0,0	0,4	0,8	0,0	2,0	8,8	0,0	7,6	0,2	3,2	0,2	0,0	6,6	0,0	2,2	72,1	27,9
SUT.	S03	64,2	3,6	30,2	2,0	1,6	35,0	0,2	27,4	0,0	0,0	0,8	0,6	0,0	0,0	2,2	0,0	4,0	12,8	0,4	9,4	0,0	3,6	0,0	0,0	1,2	0,0	0,8	72,1	27,9
SUT.	S08	76,8	2,0	18,4	2,8	0,2	26,6	0,0	49,6	0,2	0,2	0,6	0,4	0,0	0,2	0,8	0,0	3,6	8,4	0,4	3,0	0,2	2,8	0,2	0,0	1,8	0,0	0,8	81,6	18,4

Table 7.
Maceral composition of coals (Guachetá block).

BK	CODE	V	L	I	MM	VITRINITE						LIPTINITE						INERTINITE						MINERAL MATTER					REAC-TIVES	INERTS
						T	CT	VD	CD	CG	G	R	CU	SP	LD	EX	AL	FU	SF	MA	MI	FG	ID	OP	IP	CM	FM	QZ		
GUA	G13	60,2	2,0	22,4	15,4	0,0	17,8	3,4	39,0	0,0	0,0	1,0	0,4	0,0	0,0	0,6	0,0	0,8	12,8	0,6	1,8	0,0	6,4	0,2	0,8	11,8	0,4	2,2	66,5	33,5
GUA	G01	67,4	3,0	11,6	18,0	0,0	15,2	1,4	50,8	0,0	0,0	0,8	1,6	0,0	0,0	0,6	0,0	0,8	4,4	0,8	3,0	0,0	2,6	0,8	1,0	10,4	0,4	5,4	71,9	28,1
GUA	G02	70,6	4,6	21,8	3,0	0,0	29,6	0,2	40,2	0,6	0,0	1,2	2,8	0,0	0,4	0,2	0,0	1,8	8,4	1,4	6,4	0,0	3,8	0,0	0,0	2,0	0,0	1,0	78,0	22,0
GUA	G04	74,4	1,4	20,8	3,4	0,8	28,2	0,0	44,8	0,0	0,6	0,8	0,4	0,0	0,2	0,0	0,0	1,2	9,2	1,0	5,6	0,4	3,4	0,0	0,0	1,8	0,0	1,6	78,9	21,1
GUA	G18	67,2	2,0	30,0	0,8	0,8	16,6	0,0	49,2	0,0	0,6	0,2	1,0	0,0	0,4	0,4	0,0	5,8	10,0	0,8	10,6	0,0	2,8	0,0	0,0	0,0	0,0	0,8	72,5	27,5
GUA	G16	68,2	6,8	15,8	9,2	0,0	27,6	0,2	40,4	0,0	0,0	3,4	2,4	0,0	0,8	0,2	0,0	0,8	8,0	0,2	3,8	0,0	3,0	0,0	1,6	2,4	0,2	5,0	77,7	22,3
GUA	G20	76,4	5,4	13,0	5,2	0,4	18,2	0,2	57,6	0,0	0,0	1,2	1,6	0,0	2,0	0,6	0,0	0,4	4,4	0,6	6,0	0,2	1,4	0,0	0,2	2,0	1,4	1,6	83,3	16,7
GUA	G15	75,4	0,4	16,6	7,6	0,4	9,2	1,0	64,6	0,2	0,0	0,2	0,0	0,0	0,0	0,2	0,0	1,2	7,6	0,0	5,2	0,0	2,6	0,0	0,0	5,6	0,2	1,8	78,3	21,7
GUA	G12	65,8	1,6	28,4	4,2	0,4	26,2	0,0	39,0	0,0	0,2	0,4	0,0	0,0	0,0	1,2	0,0	2,2	13,2	1,0	4,2	0,4	7,4	0,2	0,0	2,2	0,0	1,8	71,8	28,2
GUA	G08	51,4	0,4	43,8	4,4	0,4	20,0	0,0	31,0	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,0	3,6	14,8	1,6	17,4	0,2	6,2	0,0	0,2	2,2	0,4	1,6	56,7	43,3
GUA	G11	83,2	0,2	14,0	2,6	0,2	11,8	0,0	71,0	0,0	0,2	0,0	0,0	0,0	0,0	0,2	0,0	2,8	5,6	0,2	3,0	0,2	2,2	0,0	0,0	1,0	0,2	1,4	85,3	14,7
GUA	G10	69,2	0,8	20,6	9,4	0,0	22,8	0,8	45,6	0,0	0,0	0,0	0,4	0,0	0,0	0,4	0,0	2,4	7,8	0,8	5,4	0,0	4,2	0,0	0,0	4,6	0,4	4,4	72,6	27,4
GUA	G14	78,6	0,6	5,4	15,4	0,0	32,4	1,8	44,4	0,0	0,0	0,2	0,2	0,0	0,0	0,2	0,0	0,2	2,8	1,0	0,4	0,0	1,0	0,0	0,0	10,2	1,4	3,8	80,1	19,9
GUA	G07	72,6	1,0	23,2	3,2	0,0	18,0	0,2	54,2	0,0	0,2	0,2	0,0	0,0	0,0	0,8	0,0	3,2	8,2	0,4	7,0	0,0	4,4	0,2	0,0	0,8	1,0	1,2	76,3	23,7
GUA	G03	66,0	4,0	27,6	2,4	0,0	16,4	0,0	49,6	0,0	0,0	2,4	0,8	0,0	0,2	0,6	0,0	0,8	16,6	1,2	4,8	0,0	4,2	0,0	0,0	0,8	0,0	1,6	75,5	24,5
GUA	G09	82,6	1,2	13,2	3,0	0,8	56,6	0,0	25,2	0,0	0,0	0,0	0,6	0,0	0,0	0,6	0,0	1,4	4,0	0,6	5,2	0,2	1,8	0,0	0,0	1,2	0,0	1,8	85,1	14,9
GUA	G06	67,0	0,8	23,8	8,4	0,0	11,2	0,0	55,6	0,0	0,2	0,0	0,0	0,0	0,0	0,8	0,0	7,2	9,0	0,2	4,8	0,0	2,6	0,2	0,0	1,6	5,4	1,2	70,8	29,2
GUA	G19	72,8	6,8	14,0	6,4	0,2	16,6	0,2	55,8	0,0	0,0	3,4	1,8	0,0	1,0	0,6	0,0	2,0	5,0	0,2	4,4	0,0	2,4	0,0	0,0	2,2	0,2	4,0	81,3	18,7
GUA	G05	68,8	0,4	26,6	4,2	0,0	9,2	0,0	59,4	0,0	0,2	0,0	0,0	0,0	0,0	0,4	0,0	10,4	9,8	0,6	2,4	0,2	3,2	0,0	0,0	0,2	0,2	3,8	72,5	27,5
GUA	G17	68,6	5,0	21,0	5,4	0,2	16,0	0,0	52,4	0,0	0,0	2,8	1,0	0,2	0,2	0,8	0,0	0,6	7,2	1,8	6,6	0,0	4,8	0,0	0,0	1,2	0,0	4,2	76,0	24,0
GUA	G21	75,4	0,6	23,0	1,0	0,0	15,4	0,0	60,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6	0,0	7,6	10,4	0,4	2,2	0,8	1,6	0,0	0,0	0,0	0,4	0,6	79,5	20,5

Table 8.

Maceral composition of coals (Samacá block).

BK	CODE	V	L	I	MM	VITRINITE						LIPTINITE						INERTINITE						MINERAL MATTER					REAC-TIVES	INERTS
						T	CT	VD	CD	CG	G	R	CU	SP	LD	EX	AL	FU	SF	MA	MI	FG	ID	OP	IP	CM	FM	QZ		
SAM	SM23	71,0	5,2	17,6	6,2	0,0	12,0	0,0	58,6	0,0	0,4	1,6	3,0	0,0	0,4	0,2	0,0	1,6	9,8	0,2	3,6	0,2	2,2	0,6	1,2	1,8	0,0	2,6	79,5	20,5
SAM	SM04	67,0	2,2	26,6	4,2	0,0	18,6	0,6	47,4	0,0	0,4	0,6	1,0	0,2	0,4	0,0	0,0	1,4	13,2	0,4	2,4	0,0	9,2	0,0	0,0	2,6	0,4	1,2	73,6	26,4
SAM	SM02	70,2	5,6	23,2	1,0	0,0	26,0	0,0	44,2	0,0	0,0	2,6	2,4	0,0	0,2	0,4	0,0	1,2	14,8	1,8	0,4	0,0	5,0	0,2	0,2	0,2	0,0	0,4	80,7	19,3
SAM	SM01	70,6	7,8	18,2	3,4	0,0	25,8	0,0	44,4	0,0	0,4	4,4	1,4	0,0	1,4	0,6	0,0	1,4	10,2	1,4	2,0	0,2	3,0	0,2	0,0	2,6	0,0	0,6	81,8	18,2
SAM	SM03	65,4	7,6	20,4	6,6	5,2	20,2	0,4	39,0	0,0	0,6	3,0	0,0	0,0	4,2	0,4	0,0	2,6	7,6	0,6	7,8	0,0	1,8	1,2	0,4	3,2	0,0	1,8	75,5	24,5
SAM	SM26	59,6	9,6	28,0	2,8	2,2	31,4	0,2	25,4	0,0	0,4	2,4	5,4	0,0	1,8	0,0	0,0	3,6	5,0	0,6	17,4	0,0	1,4	0,2	0,4	0,2	0,2	1,8	70,9	29,1
SAM	SM11	66,4	1,4	30,8	1,4	0,0	20,2	0,0	45,6	0,0	0,6	1,0	0,0	0,0	0,0	0,4	0,0	3,0	15,2	1,2	7,2	0,2	4,0	0,0	0,0	0,2	0,0	1,2	72,9	27,1
SAM	SM12	67,2	1,2	27,4	4,2	0,2	22,2	0,0	44,6	0,0	0,2	0,4	0,0	0,0	0,0	0,8	0,0	2,4	17,0	0,4	1,8	0,0	5,8	0,0	0,0	1,8	0,2	2,2	74,1	25,9
SAM	SM16	62,8	1,6	30,4	5,2	0,0	13,2	0,4	49,2	0,0	0,0	0,4	0,0	0,0	0,0	1,2	0,0	1,6	17,6	1,2	5,6	0,0	4,4	0,0	0,0	3,0	0,0	2,2	70,3	29,7
SAM	SM05	74,0	1,2	23,0	1,8	0,0	30,2	0,0	43,4	0,0	0,4	0,4	0,0	0,0	0,0	0,8	0,0	0,6	15,2	0,2	1,8	0,2	5,0	0,0	0,0	1,0	0,2	0,6	80,3	19,7
SAM	SM06	74,2	1,0	23,0	1,8	0,2	44,4	0,0	29,6	0,0	0,0	0,4	0,0	0,0	0,0	0,6	0,0	1,0	15,0	1,0	1,6	0,0	4,4	0,0	0,0	0,2	0,4	1,2	80,2	19,8
SAM	SM17	71,0	0,6	24,2	4,2	0,2	36,8	0,0	33,8	0,2	0,0	0,0	0,0	0,0	0,0	0,6	0,0	1,6	15,4	1,4	1,8	0,0	4,0	0,0	0,0	3,6	0,0	0,6	76,7	23,3
SAM	SM18	72,8	0,6	18,6	8,0	0,0	20,4	0,0	51,8	0,0	0,6	0,0	0,0	0,0	0,0	0,6	0,0	4,4	9,6	0,0	2,4	0,0	2,2	0,0	0,0	4,0	2,2	1,8	76,6	23,4
SAM	SM15	72,6	1,0	21,6	4,8	0,6	21,8	0,2	49,6	0,2	0,2	0,0	0,0	0,0	0,0	1,0	0,0	4,6	8,4	0,4	5,0	0,0	3,2	0,0	0,0	2,2	1,8	0,8	76,4	23,6
SAM	SM07	68,4	1,2	22,0	8,4	0,2	20,2	0,2	47,8	0,0	0,0	0,2	0,4	0,0	0,0	0,6	0,0	0,6	14,0	0,2	2,2	0,0	5,0	0,0	0,0	4,0	1,0	3,4	74,3	25,7
SAM	SM14	71,0	1,0	22,4	5,6	0,0	23,0	0,0	48,0	0,0	0,0	0,2	0,0	0,0	0,0	0,8	0,0	1,0	11,4	1,2	5,8	0,0	3,0	0,0	0,0	3,2	0,0	2,4	75,8	24,2
SAM	SM08	71,2	0,8	16,0	12,0	0,0	24,0	0,0	47,2	0,0	0,0	0,4	0,0	0,0	0,0	0,4	0,0	1,0	8,0	0,6	1,4	0,0	5,0	0,0	0,0	6,0	0,8	5,2	74,7	25,3
SAM	SM13	87,0	0,2	8,2	4,6	0,0	31,8	0,0	55,2	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,8	3,2	0,2	2,0	0,4	1,6	0,0	0,0	0,2	0,2	4,2	88,3	11,7
SAM	SM09	69,6	1,2	24,4	4,8	0,0	20,8	0,2	48,6	0,0	0,0	0,4	0,0	0,0	0,0	0,8	0,0	1,4	15,6	1,8	1,0	0,0	4,6	0,0	0,0	3,2	1,0	0,6	76,0	24,0
SAM	SM10	70,4	0,8	23,6	5,2	0,0	25,8	0,0	43,8	0,0	0,8	0,0	0,0	0,0	0,0	0,8	0,0	5,8	7,4	0,2	6,8	0,0	3,4	0,0	0,2	2,0	1,8	1,2	73,7	26,3
SAM	SM19	68,8	0,4	27,8	3,0	0,0	27,2	0,0	41,6	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,0	2,6	16,2	1,8	2,6	0,4	4,2	0,0	0,0	2,8	0,0	0,2	74,6	25,4
SAM	SM24	55,8	2,0	40,2	2,0	0,2	29,4	0,0	26,2	0,0	0,0	1,2	0,4	0,0	0,4	0,0	0,0	2,0	9,0	1,0	24,8	0,0	3,4	0,0	0,0	1,0	0,0	1,0	60,8	39,2
SAM	SM25	78,8	1,4	17,8	2,0	0,2	19,0	0,0	59,4	0,0	0,2	1,0	0,0	0,0	0,0	0,4	0,0	4,8	8,8	0,6	2,8	0,0	0,8	0,0	0,0	0,6	0,4	1,0	83,1	16,9
SAM	SM21	77,6	1,8	9,2	11,4	0,0	28,0	0,0	49,4	0,0	0,2	1,4	0,0	0,0	0,0	0,4	0,0	0,6	4,4	0,2	1,8	0,0	2,2	0,0	0,0	4,2	0,8	6,4	80,9	19,1
SAM	SM20	71,0	1,4	24,0	3,6	0,0	23,0	0,0	48,0	0,0	0,0	0,4	0,2	0,0	0,0	0,8	0,0	2,2	15,8	0,4	2,0	0,0	3,6	0,0	0,0	0,6	2,4	0,6	77,7	22,3
SAM	SM22	73,8	1,8	23,0	1,4	0,0	14,8	0,0	58,6	0,0	0,4	0,2	0,0	0,0	0,0	1,6	0,0	4,4	10,0	0,8	5,8	0,4	1,6	0,2	0,0	0,0	0,0	1,2	78,9	21,1

LEGEND

Maceral groups and mineral matter

L: Liptinite
I: Inertinite
MM: Mineral matter

Vitrinite group

T: Telinite
CT: Collotelinite
VD: Vitrodetrinite
CD: Collodetrinite
CG: Corpogelinite
G: Gelinite

Liptinite group
R: Resinite
CU. Cutinite
SP: Sporinite
LD: Liptodetrinite
EX: Exudatinite
AL: Alginite

Inertinite group
FU: Fusinite
SF: Semifusinite
MA: Macrinite
MI: Micrinite
FG: Funginite
ID: Inertodetrinite

Mineral matter
OP: organic pyrite
IP: Inorganic pyrite
CM: clay minerals
FM: Ferrous minerals
QZ: Quartz

4. CHAPTER FOUR: TEST RESULTS AND CLASSIFICATIONS

Sixty four (64) samples of coal were recollected in underground mines with the channel method (ASTM D2234/ D2234M-16), so they were prepared in the laboratory to make different test (Moisture, ash, volatile mater, sulfur, fixed carbon, FSI and petrography) with the purpose of classifying them and determine the variation of their properties with the depositional environments and depth. Twelve (12) seams of coal were sampled in the Sutatausa block, sixteen (16) for the Guachetá block and fourteen (14) for the Samacá block as is shown in the table 9.

Table 9.
N# of samples and seams of coal for each block.

LOCALITIES	MINES	SAMPLES	SEAMS
Sutatausa	14	17	13
Guachetá	7	21	17
Samacá	10	26	14

With the determination of the proximate analysis the coals were classified with the ASTM D388-12 norm using the Parr equations (Equation 2 and 3) according with the dry volatile matter free of mineral matter, the results showed that samples are Bituminous coals (Low, medium and high volatile). The ISO 11760 norm uses the medium reflectance of vitrinite for the classification, for this method the samples were classified as bituminous coals type A, B and C.

$$\mathrm{FC\ (D, Mm - free)} = \frac{100\ (\mathrm{FC} - 0.155\ \mathrm{S})}{0.01100 - (\mathrm{M} + 1.08\mathrm{A} + 0.55\ \mathrm{S})}$$

Equation 2. Parr equation to determine the fixed carbon (Dry, mineral matter free).

FC: Fixed carbon (Dry, mineral matter free)
FC: Fixed carbon
S: Sulfur
M: Moisture
A: Ash

$$\mathrm{VM\ (d, Mm - free)} = 100 - \mathrm{FC\ (D, Mm - free)}$$

Equation 3. Parr equation to determine the volatile matter (Dry, mineral matter free).

VM: Volatile matter (Dry, mineral matter free)
FM: Fixed carbon (Dry, mineral matter free)

4.1. PROXIMATE ANALYSIS + REFLECTANCE OF VITRINITE

4.1.1. Sutatausa results.

For this block were found the coals with the lower rank in comparison with the other blocks. The proximate analysis are show in the table 10, so it is appreciable like the shallower coals present higher values of moisture and volatile matter, the range for these features were 0.65% to 1.49% and 26.79% to 35.73% respectively likewise the coals with the highest rank are in the lower part of the stratigraphic column.

The higher values of ash corresponding to the La Grande 2 and Deposito seams with percentages up 20.00%, possibly as result of the depositional environment. The sulfur content showed values from 0.42% to 0.62% which correspond with the petrographic analysis (Pyrite content). The FSI test shows good properties of agglomeration for all coals so it is possible that can be used in the coke production like unitary component or in mixtures.

Thirteen (13) of the seventeen (17) recollected samples for this block were classified like high volatile A bituminous coals as is shown in the table 11 according with the ASTM norm due to the volatile matter dry mineral matter free content was above 31%, and the other four (4) as medium volatile bituminous coals.

For the ISO 11760 norm all samples (17) were classified like Bituminous coals type C, due anyone had values of medium reflectance of vitrinite above 1.00%. The range of reflectance was between 0.69% and 0.98%.

Table 10.
Proximate analyses of the Sutatausa block coals.

BLOCK	CODE	SEAM	THICKNESS	M	T.M	A	VM	FC	FSI	S (Db)
SUTATAUSA	S14	7 BANCOS SUPERIOR	2,34	1,15	2,47	12,43	35,72	50,70	4,50	1,48
SUTATAUSA	S13	DEPOSITO	0,83	1,29	2,41	22,84	31,88	43,99	3,00	1,61
SUTATAUSA	S11	CISCUDA	1,18	0,87	2,08	10,04	31,92	57,16	8,50	1,14
SUTATAUSA	S10	CISCUDA	1,70	0,88	2,39	9,32	31,75	58,06	8,00	0,74
SUTATAUSA	S09	CHICA 3	1,02	1,01	2,36	8,34	32,98	57,66	8,50	0,67
SUTATAUSA	S12	QUINTAS	1,70	1,49	3,75	5,84	30,95	61,72	8,00	0,44
SUTATAUSA	S17	GRANDE 2	1,37	0,86	2,21	24,80	26,79	47,26	8,50	0,92
SUTATAUSA	S16	CHICA 2	0,78	0,65	1,66	2,72	33,15	63,26	8,50	0,56
SUTATAUSA	S15	7 BANCOS INFERIOR	1,35	0,87	2,44	11,27	28,91	59,06	8,00	0,42
SUTATAUSA	S07	GEMELA SUPERIOR	0,30	0,75	1,80	9,11	28,79	61,41	8,00	0,54
SUTATAUSA	S05	GEMELA SUPERIOR	0,80	0,81	5,63	4,28	31,94	62,98	7,00	0,52
SUTATAUSA	S06	GEMELA INFERIOR	0,70	0,69	2,06	6,98	30,84	61,37	7,50	0,59
SUTATAUSA	S04	GEMELA INFERIOR	0,90	0,74	2,99	6,82	27,60	64,84	8,50	0,42
SUTATAUSA	S01	LA GRANDE 1	1,40	0,81	1,84	7,08	30,43	61,64	8,50	0,56
SUTATAUSA	S02	LA GRANDE 1	1,35	1,16	3,36	7,26	28,23	63,86	8,50	0,50
SUTATAUSA	S03	CHICA 1	1,02	0,73	2,68	3,22	29,03	67,03	8,00	0,53
SUTATAUSA	S08	VETA PRIMERA	0,50	0,82	1,68	6,20	28,29	64,70	8,00	0,94

M: Moisture **TM:** Total moisture **A:** Ash **VM:** Volatile matter **FC:** Fixed carbon **FSI:** Swelling index **S(Db):** Sulfur (Dry basis)

Table 11.
Classification of coals with the ASTM and ISO norms (Sutatausa block).

CODE	Rom	FC (D, Mm-free)	VM (D, Mm-free)	ASTM	ISO
S14	0,69	59,65	40,35	H.V.A.B	B.C
S13	0,75	59,78	40,22	H.V.A.B	B.C
S11	0,79	65,01	34,99	H.V.A.B	B.C
S10	0,81	65,37	34,63	H.V.A.B	B.C
S09	0,82	64,23	35,77	H.V.A.B	B.C
S12	0,85	67,04	32,96	H.V.A.B	B.C
S17	0,88	65,57	34,43	H.V.A.B	B.C
S16	0,89	65,74	34,26	H.V.A.B	B.C
S15	0,88	68,03	31,97	H.V.A.B	B.C
S07	0,91	68,82	31,18	H.V.A.B	B.C
S05	0,92	66,71	33,29	H.V.A.B	B.C
S06	0,94	67,01	32,99	H.V.A.B	B.C
S04	0,95	70,66	29,34	M.V.B	B.C
S01	0,93	67,46	32,54	H.V.A.B	B.C
S02	0,94	70,31	29,69	M.V.B	B.C
S03	0,98	70,10	29,90	M.V.B	B.C
S08	0,95	70,19	29,81	M.V.B	B.C

ASTM D388-12

LA: Lignite A
LB: Lignite B
SBA: Sub-Bituminous A
SBB: Sub-Bituminous B
SBC: Sub-Bituminous C
HVAB: High volatile A bituminous
HVBB: High volatile B bituminous
HVBC: High volatile C bituminous
MVB: Medium volatile bituminous
LVB: Low volatile bituminous
SA: Semi anthracite
A: Anthracite
MA: Meta anthracite

ISO 11760

LB. Lignite B
LC: Lignite C
SA: Subbituminous A
BA: Bituminous type A
BB: Bituminous type B
BC: Bituminous type C
BD: Bituminous type D
AA: Anthracite A
AB: Anthracite B
AC: Anthracite C

4.1.2. Guachetá results.

For this block were found the coals with the higher rank in comparison with the other blocks. The proximate analyses are shown in the table 12; the moisture and volatile matter decrease with the increase of rank but is not a linear relationship.

The highest values of ash corresponding at the Siete Bancos and Suncho Cisquera seams with percentages of 16.66% and 15.31%, possibly as result of the depositional environment. The sulfur content showed values from 0.34% to 1.85% which correspond with the petrographic analysis (Pyrite content). The FSI test shows good properties of agglomeration for the most of coals except the Gemelas seam, so it is possible that the rest can be used in the coke production like unitary component or in mixtures.

In this section one (1) coal was classified as high volatile bituminous type A, ten (10) as medium volatile bituminous and ten (10) more as low volatile bituminous (Table 13) according with the ASTM norm. For the Iso 11760 norm two (2) samples were classified like bituminous coals type C, twelve (12) as type B and six (7) as type A.

Table 12.
Proximate analyses of the Guachetá block coals.

BLOCK	CODE	SEAM	THICKNESS	M	T.M	A	VM	FC	FSI	S (Db)
GUACHETÁ	G13	7 BANCOS	2,35	0,68	3,70	16,66	24,58	58,08	7,50	1,26
GUACHETÁ	G01	SUNCHO CISQUERA	0,41	0,26	3,37	15,31	25,92	58,51	8,00	0,82
GUACHETÁ	G02	CISQUERA NIVEL 80	1,05	0,38	3,11	5,27	29,67	64,68	8,00	0,91
GUACHETÁ	G04	CISQUERA NIVEL 180	1,60	0,54	4,49	5,17	29,02	65,27	7,50	0,49
GUACHETÁ	G18	CISQUERA (NIVEL300)	1,00	0,68	3,30	2,52	27,07	69,72	8,50	1,85
GUACHETÁ	G16	VETA GRANDE	0,70	0,87	3,13	9,50	27,45	62,18	8,50	1,36
GUACHETÁ	G20	MANTO 2	0,70	0,63	3,01	10,41	30,15	58,81	8,00	0,49
GUACHETÁ	G15	BOCATOMA NIVEL 220	1,40	0,66	7,50	8,79	19,78	70,77	8,00	0,57
GUACHETÁ	G12	PIEDRO	0,75	0,71	5,91	5,93	20,27	73,10	8,50	0,66
GUACHETÁ	G08	BOLAS	0,70	0,51	1,68	10,74	22,81	65,93	5,00	0,73
GUACHETÁ	G11	CONSUELO SUPERIOR	0,75	0,41	3,44	9,21	19,76	70,62	8,00	0,48
GUACHETÁ	G10	CONSUELO	0,40	0,25	3,18	10,75	17,50	71,50	8,00	0,41
GUACHETÁ	G14	PLANTA DE SODA	0,20	0,84	1,89	13,31	18,72	67,13	3,50	0,46
GUACHETÁ	G07	GEMELAS	1,52	0,53	1,84	6,47	19,48	73,53	8,50	0,63
GUACHETÁ	G03	CUARTAS	0,50	0,48	3,01	4,41	28,05	67,06	8,50	0,46
GUACHETÁ	G09	MILAGROS	0,80	0,81	1,64	4,91	20,69	73,59	8,00	0,50
GUACHETÁ	G06	TESORO	1,50	0,55	6,89	10,41	16,62	72,42	7,50	0,35
GUACHETÁ	G19	TESORO	0,70	0,51	2,30	8,16	28,63	62,70	8,50	0,57
GUACHETÁ	G05	TESORITO	0,70	0,48	5,42	6,75	17,66	75,11	8,00	0,34
GUACHETÁ	G17	TESORITO	-	0,79	3,31	5,88	29,25	64,08	8,50	0,62
GUACHETÁ	G21	CISQUERA INFERIOR	0,80	0,55	5,47	3,86	17,02	78,58	8,00	0,40

M: Moisture **TM:** Total moisture **A:** Ash **VM:** Volatile matter **FC:** Fixed carbon **FSI:** Swelling index **S(Db):** Sulfur (dry basis)

Table 13.
Classification of coals with the ASTM and ISO norms (Guachetá block).

CODE	Rom	FC (D, Mm-free)	VM (D, Mm-free)	ASTM	ISO
G13	1,01	71,79	28,21	M.V.B	B.B
G01	1,03	70,55	29,45	M.V.B	B.B
G02	1,06	69,08	30,92	M.V.B	B.B
G04	1,07	69,64	30,36	M.V.B	B.B
G18	1,08	72,65	27,35	M.V.B	B.B
G16	0,96	70,32	29,68	M.V.B	B.C
G20	0,94	66,85	33,15	H.V.A.B	B.C
G15	1,39	78,95	21,05	L.V.B	B.B
G12	1,25	78,89	21,11	L.V.B	B.B
G08	1,29	75,24	24,76	M.V.B	B.B
G11	1,38	78,93	21,07	L.V.B	B.B
G10	1,48	81,26	18,74	L.V.B	B.A
G14	1,40	79,33	20,67	L.V.B	B.A
G07	1,44	79,69	20,31	L.V.B	B.A
G03	1,03	70,88	29,12	M.V.B	B.B
G09	1,45	78,53	21,47	L.V.B	B.A
G06	1,52	82,22	17,78	L.V.B	B.A
G19	1,05	69,29	30,71	M.V.B	B.B
G05	1,53	81,54	18,46	L.V.B	B.A
G17	1,01	69,16	30,84	M.V.B	B.B
G21	1,60	82,59	17,41	L.V.B	B.A

ASTM D388-12

LA: Lignite A
LB: Lignite B
SBA: Sub-Bituminous A
SBB: Sub-Bituminous B
SBC: Sub-Bituminous C
HVAB: High volatile A bituminous
HVBB: High volatile B bituminous
HVBC: High volatile C bituminous
MVB: Medium volatile bituminous
LVB: Low volatile bituminous
SA: Semi anthracite
A: Anthracite
MA: Meta anthracite

ISO 11760

LB. Lignite B
LC: Lignite C
SA: Subbituminous A
BA: Bituminous type A
BB: Bituminous type B
BC: Bituminous type C
BD: Bituminous type D
AA: Anthracite A
AB: Anthracite B
AC: Anthracite C

4.1.3. Samacá results.

The moisture for this section was between 0.16% and 1.13% and the volatile matter between 18.02% and 33.5% (Table 14). The highest values of ash corresponding at the Siete Bancos and Piedro intermedio seams with percentages of 12.59% and 11.95%, possibly as result of the depositional environment. The sulfur content showed values from 0.45% to 1.82% which correspond with the petrographic analysis (Pyrite content). The FSI test shows good properties of agglomeration for all coals that can be used in the production of coke.

In this section four (4) coals were classified as high volatile bituminous type A, fourteen (15) as medium volatile bituminous and eight (7) more as low volatile bituminous (Table 15) according with the ASTM norm. For the Iso 11760 norm six (6) samples were classified lie bituminous coals type C, fourteen (14) as type B and six (6) as type A.

Table 14.
Proximate analyses of the Samacá block coals.

BLOCK	CODE	SEAM	THICKNESS	M	T.M	A	VM	FC	FSI	S (Db)
SAMACA	SM23	SIETE BANCOS	1,00	1,13	3,48	12,59	26,46	59,83	7,50	1,82
SAMACA	SM04	LA GRANDE	3.0-1.6	0,77	2,14	10,32	27,37	61,54	8,00	1,08
SAMACA	SM02	TERCERA INFERIOR	0,80	0,63	2,86	5,98	32,86	60,53	8,00	1,55
SAMACA	SM01	TERCERA SUPERIOR	0,80	0,69	2,56	4,99	33,50	60,83	8,00	1,12
SAMACA	SM03	TER. (LA LIGADA)	0,90	0,84	2,23	10,98	30,67	57,51	8,00	1,47
SAMACA	SM26	LIGADA	0,85	1,00	3,02	6,33	30,40	62,27	8,00	1,11
SAMACA	SM11	PERDIDA SUPERIOR	0,55	0,41	1,97	4,21	22,90	72,48	8,50	0,60
SAMACA	SM12	PERDIDA INFERIOR	0,40	0,47	3,79	4,82	22,76	71,95	8,50	0,69
SAMACA	SM16	BOCATOMA	1,10	0,75	2,66	5,11	21,83	72,31	7,00	0,49
SAMACA	SM05	BOCATOMA	1,60	0,48	2,02	4,49	21,33	73,70	8,00	0,46
SAMACA	SM06	RUBI	0,92	0,49	4,16	4,46	22,00	73,05	8,00	0,51
SAMACA	SM17	RUBI SUPERIOR	0,80	0,54	2,72	6,04	18,09	75,33	8,50	0,55
SAMACA	SM18	RUBI INFERIOR	0,18	0,23	2,43	8,50	18,02	73,25	8,00	0,55
SAMACA	SM15	PIEDRO SUPERIOR	0,25	0,56	3,34	8,20	19,64	71,60	8,00	0,62
SAMACA	SM07	PIEDRO INTERMEDIO	0,50	0,52	4,04	11,95	20,55	66,98	8,50	0,51
SAMACA	SM14	PIEDRO MEDIO	0,60	0,45	2,26	5,83	21,12	72,61	8,50	0,56
SAMACA	SM08	PIEDRO INFERIOR	0,56	0,61	3,17	8,05	21,93	69,41	8,50	0,70
SAMACA	SM13	PIEDRO INFERIOR	0,48	0,49	4,38	8,42	21,17	69,93	8,50	0,64
SAMACA	SM09	CONSUELO SUPERIOR	0,70	0,69	4,32	8,05	19,24	72,02	8,50	0,57
SAMACA	SM10	CONSUELO INTERMEDIO	0,70	0,47	2,74	8,43	21,35	69,75	8,50	0,57
SAMACA	SM19	CONSUELO	0,80	0,16	2,34	5,60	19,27	74,97	8,00	0,56
SAMACA	SM24	GEMELA SUPERIOR	0,80	0,87	1,84	6,62	25,29	67,22	8,00	0,52
SAMACA	SM25	GEMELA INFERIOR	0,87	0,90	1,65	4,46	24,17	70,47	8,00	0,53
SAMACA	SM21	TESORO	0,54	0,62	3,31	9,15	24,09	66,14	8,00	0,48
SAMACA	SM20	TESORITO	0,50	0,48	2,69	6,54	20,94	72,04	8,00	0,45
SAMACA	SM22	CISCUDA (CISQUERA)	0,90	0,64	2,78	4,86	21,78	72,72	8,00	0,45

M: Moisture **TM:** Total moisture **A:** Ash **VM:** V. matter **FC:** F. carbon **FSI:** Swelling index **S(Db):** Sulfur (dry basis)

Table 15.
Classification of coals with the ASTM and ISO norms (Samacá block).

CODE	Rom	FC (D, Mm-free)	VM (D, Mm-free)	ASTM	ISO
SM23	0,93	70,65	29,35	M.V.B	B.C
SM04	0,93	70,15	29,85	M.V.B	B.C
SM02	0,85	65,49	34,51	H.V.A.B	B.C
SM01	0,89	65,00	35,00	H.V.A.B	B.C
SM03	0,84	66,23	33,77	H.V.A.B	B.C
SM26	0,91	67,83	32,17	H.V.A.B	B.C
SM11	1,27	76,43	23,57	M.V.B	B.B
SM12	1,29	76,47	23,53	M.V.B	B.B
SM16	1,33	77,29	22,71	M.V.B	B.B
SM05	1,41	77,99	22,01	M.V.B	B.A
SM06	1,29	77,29	22,71	M.V.B	B.B
SM17	1,41	81,23	18,77	L.V.B	B.A
SM18	1,45	81,04	18,96	L.V.B	B.A
SM15	1,44	79,23	20,77	L.V.B	B.A
SM07	1,30	77,52	22,48	M.V.B	B.B
SM14	1,41	78,03	21,97	L.V.B	B.A
SM08	1,22	76,74	23,26	M.V.B	B.B
SM13	1,32	77,53	22,47	M.V.B	B.B
SM09	1,34	79,66	20,34	L.V.B	B.B
SM10	1,31	77,31	22,69	M.V.B	B.B
SM19	1,41	80,10	19,90	L.V.B	B.A
SM24	1,24	73,22	26,78	M.V.B	B.B
SM25	1,23	74,89	25,11	M.V.B	B.B
SM21	1,25	74,04	25,96	M.V.B	B.B
SM20	1,27	78,05	21,95	L.V.B	B.B
SM22	1,33	77,40	22,60	M.V.B	B.B

ASTM D388-12
LA: Lignite A
LB: Lignite B
SBA: Sub-Bituminous A
SBB: Sub-Bituminous B
SBC: Sub-Bituminous C
HVAB: High volatile A bituminous
HVBB: High volatile B bituminous
HVBC: High volatile C bituminous
MVB: Medium volatile bituminous
LVB: Low volatile bituminous
SA: Semi anthracite
A: Anthracite
MA: Meta anthracite

ISO 11760
LB. Lignite B
LC: Lignite C
SA: Subbituminous A
BA: Bituminous type A
BB: Bituminous type B
BC: Bituminous type C
BD: Bituminous type D
AA: Anthracite A
AB: Anthracite B
AC: Anthracite C

4.2. CORRELATION (PROPERTIES)

Some properties of coals (Physical, chemical and petrographic) can be present correlation with others like result of the ranks increase, depositional environments and precursor vegetation. In the figure 15 is presented the relation between the volatile matter and the random reflectance of vitrinite, this graphic shows an inverse linear trend; when the volatile matter decrease the reflectance of vitrinite increase which indicate that coals in the coalification process release gases due the gain of temperature and the lithostatic pressure. The red stripe indicates the absence of coals with random vitrinite reflectance from 1.10% to 1.2%. Coals with values above and below of this rank are found in the study area and they are separated by the "key bed 1" in the stratigraphic column along the three sections of the Checua-Lenguazaque syncline.

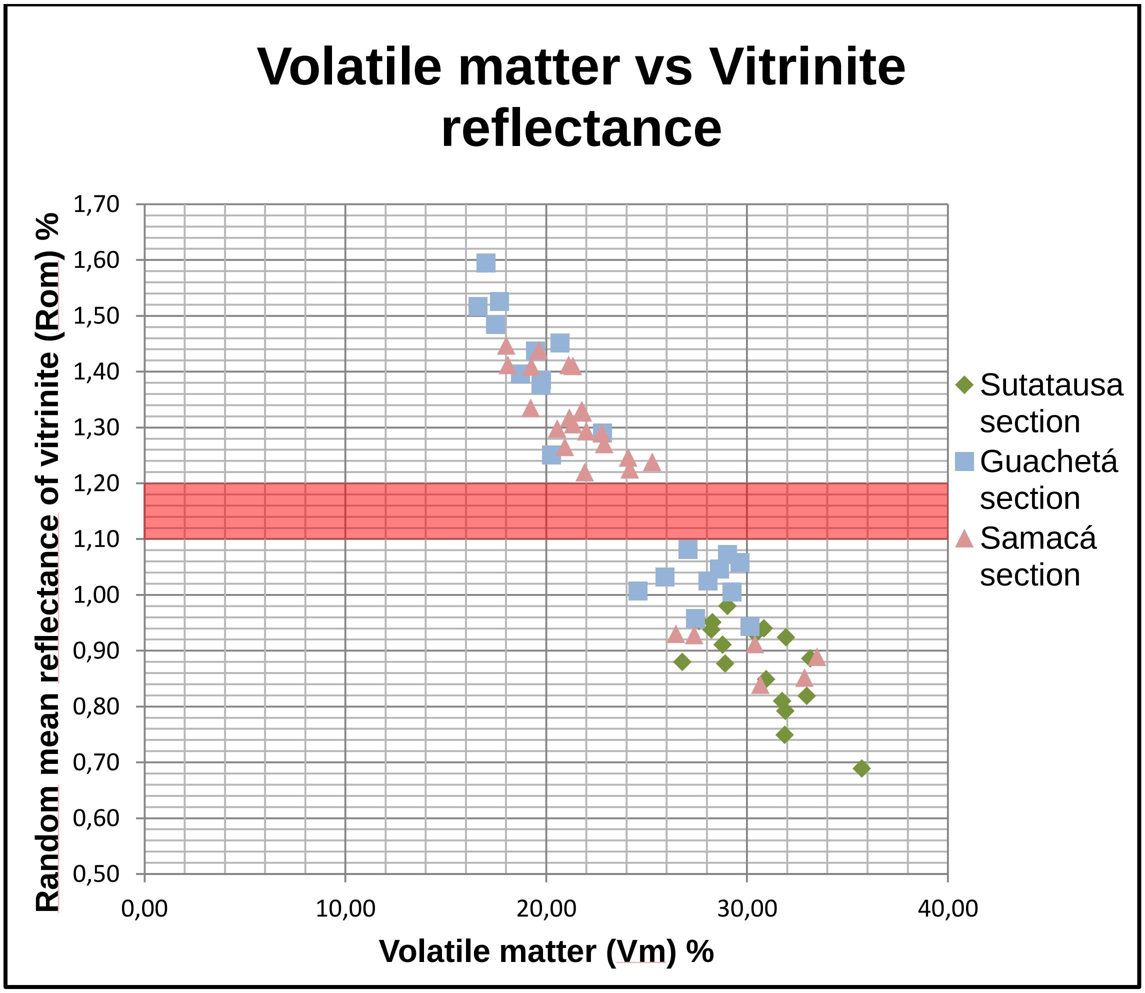

Figure 15. Correlation between volatile matter and random reflectance of vitrinite (Basis as determined).

The direct correlation between the proximate analysis and petrographic can be established with the ash content and mineral matter and it is presented in the figure 16. The relation of these properties has a linear correlation due both tests give information about the content of inorganic constituents in the coals. The ash test allows obtain the measure of mineral matter after combustion in mass terms, while the petrographic analysis provides the same information (Mineral matter content) but in volumetric terms. Values of ash and mineral matter above 10.00% were found in whole study area, however higher values are present in the Guachetá (7 Bancos and Suncho Chisquera seams) and Sutatausa (Deposito and Grande 2 Seams) sections where the ash content is above 15.00%. These values show evidence of stronger water influxes in the peat stage (Vessey & Bustin, 2000) increasing the mineral matter content due the sediment transport.

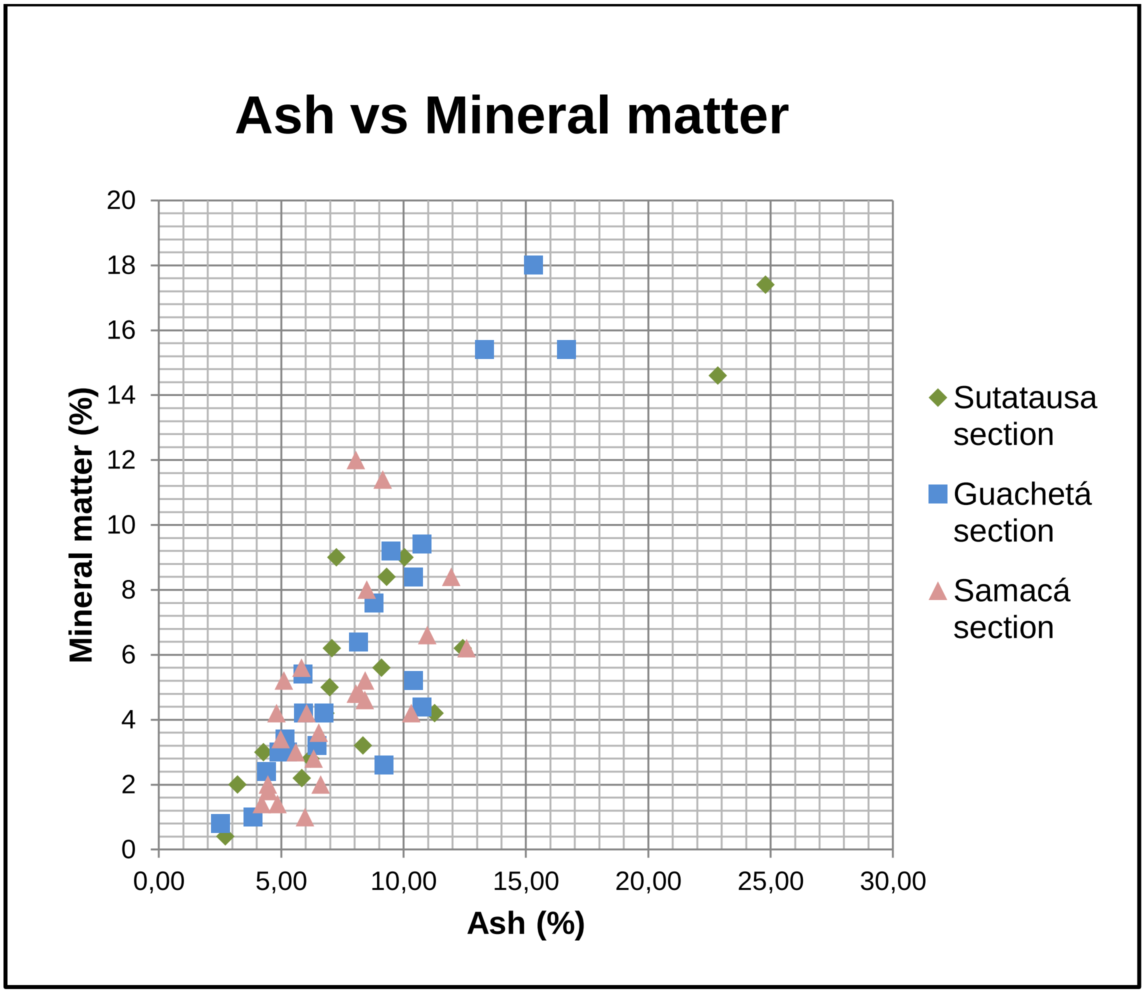

Figure 16. Correlation between ash and mineral matter (Basis as determined).

5. CHAPTER FIVE: DEPOSITIONAL ENVIRONMENTS - RESULTS

5.1. PETROGRAPHIC INDICES

The petrographic indices are the result of the aggrupation of the maceral constituents and different math operations that provide information about environments where were deposited the coals seams. Diessel (1986) proposed the gelification index (GI) and the tissues preservation index (TPI) to use the diagram modified by Alves (1996) and determine the predominant conditions in the peat stage.

TPI: The tissues preservation index shows the relation between the destroyed organic components and the constituent what are texturally and mechanilly preserved (Diessel, 1986). The equation 5 presents the used macerals to calculate this index according with the maceral reading.

$$\mathrm{TPI} = \frac{\mathrm{Telinite} + \mathrm{Collotelinite} + \mathrm{Semifusinite} + \mathrm{Fusinite}}{\mathrm{Collodetrinite} + \mathrm{Macrinite} + \mathrm{Inertodetrinite}}$$

Equation 4. Determination of the tissues preservation index (TPI).

GI: The gelification index indicates the relation between gelled and oxidized components (Equation 6); the first ones are formed in saturated conditions while the second ones are formed in subaereous conditions (Diessel, 1986).

$$\mathrm{GI} = \frac{\mathrm{Vitrinite} + \mathrm{Macrinite}}{\mathrm{Semifusinite} + \mathrm{Fusinite} + \mathrm{inertodetrinite}}$$

Equation 5. Determination of gelification index (GI).

Using both indices is possible distinguish five depositional environments: Lower Delta Plain, Upper Delta Plain, Alluvial Valley, Piedmont Plain and Back Barrier (Alves & Ade, 1996). The results for the three sections of the Checua-Lenguazaque syncline are presented in the figures 17, 18 and 19. Low values of TPI are associated with high proportions of collodetrinite, formed it by high PH and particles transport in a determined environment with the fresh water action which favors the degradation of the organic matter (Jiménez , Martinez Tarazona, & Suárez Ruiz, 1999). The highest values of GI are the result of a constant water table as product of marine incursions with calcium rich water allowing the fast decomposition of the precursor of vitrinite macerals (Jiménez , Martinez Tarazona, & Suárez Ruiz, 1999), (Guatame & Sarmiento, 2004), (Mejia Umaña, et al., 2006).

5.1.1. Sutatausa section (TPI & GI).

The results for the TPI and GI diagram for this section are shown in the figure 17. The environmental parameters oscillate between telmatic (Terrestrial) and limno-telmatic (Terrestrial - underwater) conditions. The coal seams were present in three different environments, upper delta plains (Wet forest swamps); lower delta plains (Marshes) and back barrier zones with transgressive events. Any coal of this section was deposited in piedmont plains and fluvial valleys (Strand plain coal), so the higher values of collotelinite are present in the right part of the diagram evidencing that these coals were deposited in upper delta plains as La Grande 1 seam. The 7 Bancos and Veta primera conversely were deposited in back barrier zones (Left part of the diagram) with more influence of calcium rich waters presenting higher values of Collodetrinite. The rest of coal samples of this section were deposited in an interval between the upper and lower delta plains.

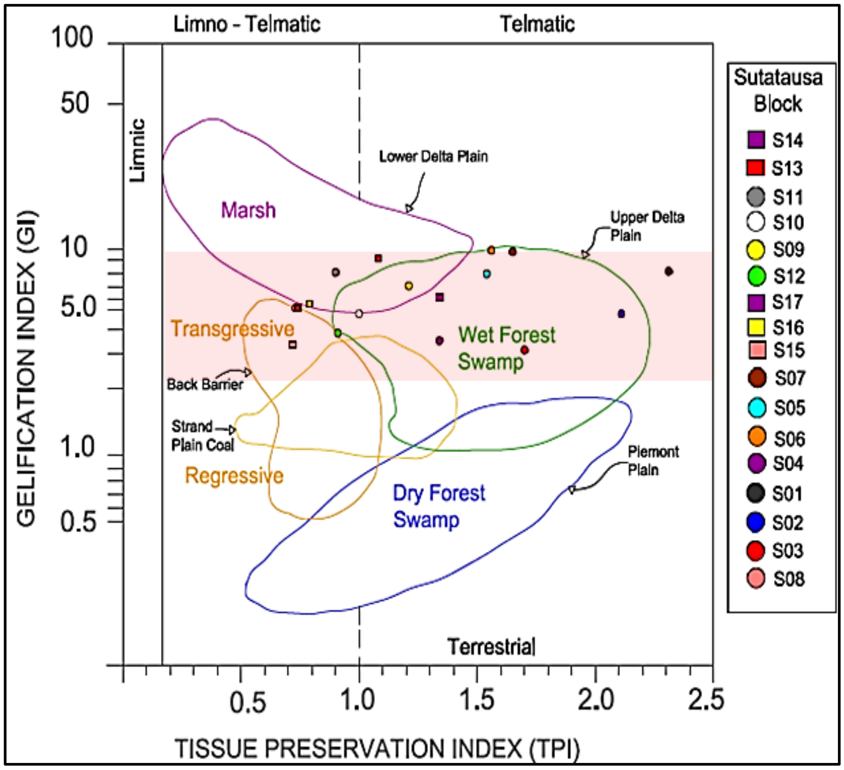

Figure 17. Facies diagram for identification paleodepositional peat-forming environments – Sutatausa section - modified from (Diessel, 1986) and (Alves & Ade, 1996).

5.1.2. Guachetá section (TPI & GI).

The facies diagram from Diessel (1986) in this section is presented in the figure 18. The coals from this section were deposited mainly in limno-telmatic conditions except the Milagros seam that was deposited in the limit between upper and lower delta plains in a telmatic zone (Increase of tree density) according with a high TPI value (Singh & Singh, 2000). The rest of seams were deposited mainly in three environments, lower delta plains (Marshes), back barrier zones and fluvial valleys (Strand plain coals).

The obtained samples from Guachetá presented higher content of collodetrinite due the marine incursions allowing the decomposition of the precursor organic matter destroying the original tissues of vegetation. It is appreciable like coals from this block had greater influence of marine waters with calcium content; the high concentration of calcium ions accelerates the decomposition of organic matter and the formation of humates (Singh & Singh, 2000), which is according with the stratigraphic studies in the zone and the transgressive and regressive periods showed by the Guaduas Formation during its deposition (Amaya Medina, 2009).

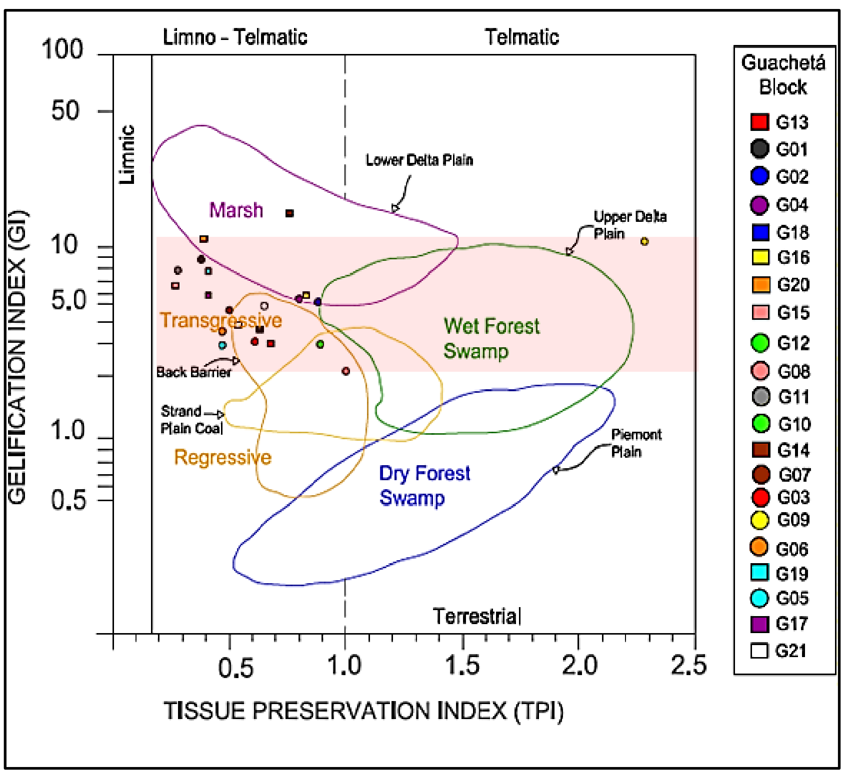

Figure 18. Facies diagram for identification paleodepositional peat-forming environments – Guachetá section - modified from (Diessel, 1986) and (Alves & Ade, 1996).

5.1.3. Samacá section (TPI & GI).

The Samacá section presents similar facies to the Guachetá section dominated for marshes, strand plains, back barriers and wet forest swamps facies in four major environments, lower delta plains, alluvial valleys, upper delta plains, and back barrier zones with limno-telmatic to telmatic conditions how is represented in the figure 19. The influence of marine incursions in this area is important too since it is evidenced in the degradation of the deposited organic matter in the peat bog (Diessel, 1986) (Mejía Umaña et al., 2006). The combination of low values of TPI (<1) and medium values of GI (<5) allows to define the depositional environment where the coals were deposited as back barrier zones with influence of marine water incursions producing high values of collodetrinite reflecting increments in the sediment and organic material transport in the environment (Buillit, Lallier, Nicolas, & Pradier, 2002). Any coal seam in this section was deposited in piedmont plains (Dry forest swamps) due the major component of coals from the Guaduas Formation are the macerals of the vitrinite group (Guatame & Sarmiento, 2004) (Mejía Umaña et al., 2006) (Gómez Neita et al., 2016).

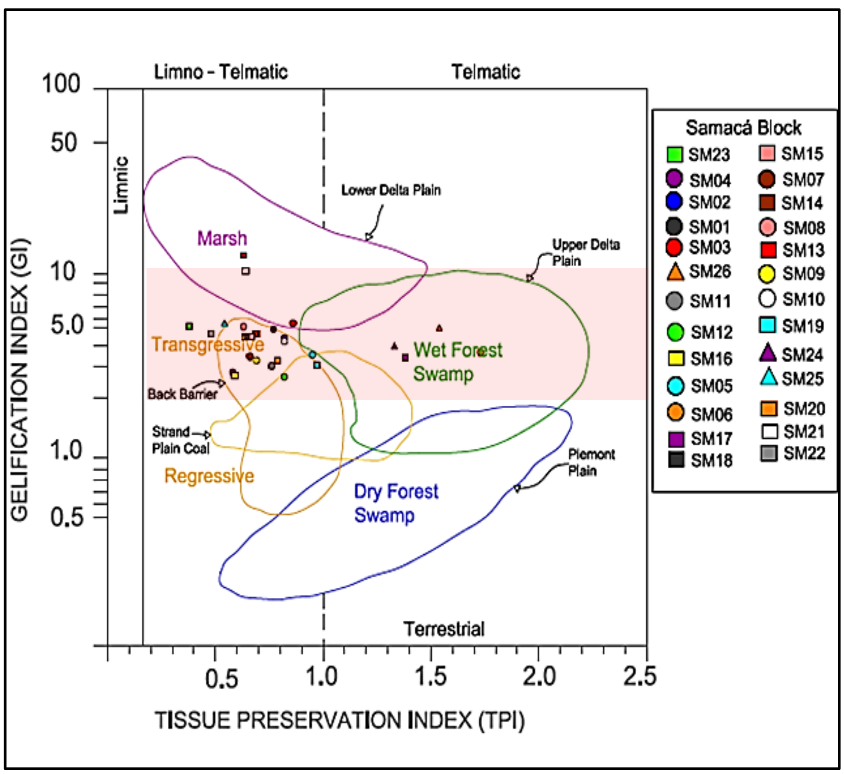

Figure 19. Facies diagram for identification paleodepositional peat-forming environments – Samacá section - modified from (Diessel, 1986) and (Alves & Ade, 1996).

Another facies model based on the vegetation index (VI) and groundwater index (GWI) is proposed by Calder, Gibbing, & Mukhopadhay (1991) to stablish the peatland history according with the ground water influence and its changes, rainfall action, vegetation, mineral mater and preservation of the organic matter (Calder et al., 1991) (Singh & Singh, 2000). The diagram used with these indices allows determining the environment where the coals were deposited and the origin of nutrients in the peat stage.

VI: The vegetation index is a relation between macerals of herbaceous vegetation and macerals with wood affinity showing an approximate idea of the environment where that organic matter developed (Calder et al., 1991). The used macerals to calculate VI are presented in the Equation 6.

$$\mathrm{VI} = \frac{\mathrm{Telinite + Collotelinite + Semifusinite + Fusinite + Sclerotinite + Resinite}}{\mathrm{Collodetrinite + Inertodetrinite + Alginite + Liptodetrinite + Cutinite}}$$

Equation 6. Determination of the vegetation index (VI).

GWI: The groundwater index is a relation of gelled macerals and not gelled macerals (Equation 7) establishing a relative level of water with its nutrient sources (Calder et al., 1991).

$$\mathrm{GWI} = \frac{\mathrm{Gelinite + Corpogelinite + Mineral\ matter + Vitrodetrinite}}{\mathrm{Telinite + Collotelinite + Collodetrinite}}$$

Equation 7. Determination of the groundwater index (VI).

Low values of VI indicate a higher content of collodetrinite of coals and they have relation with the precursor vegetation and the environment where the material was deposited (Herbaceous vegetation), while high values indicate arboreal vegetation. Lower values of GWI evidence a low water level too, so the nutrients came from rainfalls while high values show a peatland with a high level of water where the nutrients proceed from the underground and lateral waters (Calder et al., 1991) (Jiménez et al., 1999).

5.1.4. Sutatausa section (VI & GWI).

Coals deposited in this section presented low values of VI (<3) indicating a bog environment where the predominant vegetation correspond to herbaceous plants according with the presented diagram in the figure 20. The conditions of this type of environment (Bog) do not allow supporting large plant life evidencing macerals with low woody tissues preservation. The model proposed by Calder, et al. (1991) is used in Permian coals from Australia and Westphalian, nevertheless is not checked that age has control in the principles of peat formation (Singh & Singh, 2000) and this model was used for these coals (Guaduas Formation).

Low values of GWI show for these coals that nutrients came from rainfall water indicating ombotrophic conditions; the mineral matter is an evidence of high interaction of water (Vessey & Bustin, 2000) in the peatbog therefore the Deposito and la Grande 2 seams present a mesotrophic tendency according with the hydrology features.

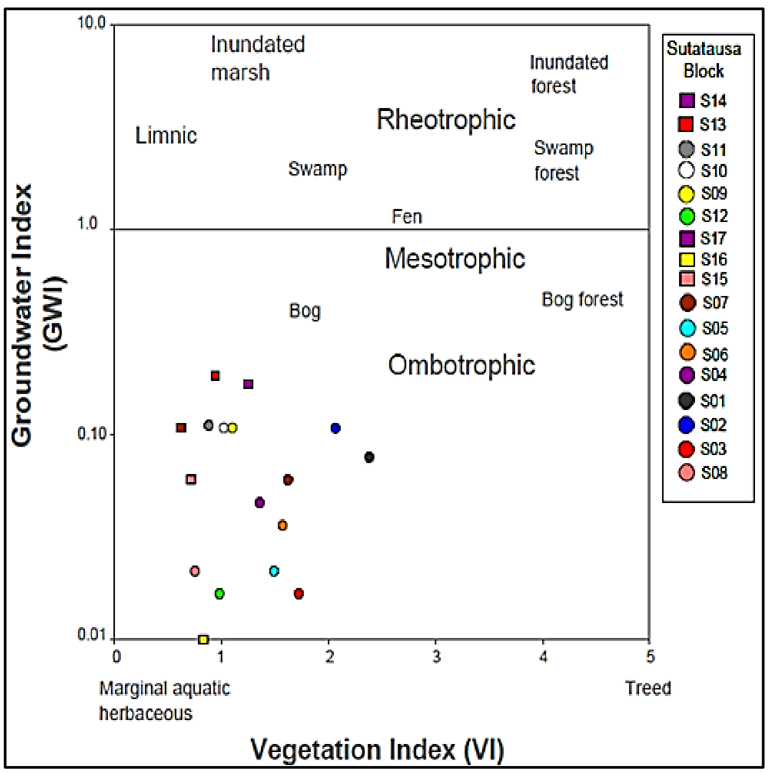

Figure 20. GW/VI mire paleoenvironment diagram of coals of the Guaduas Formation coals, Sutatausa section modified from Calder et al. (1991)

5.1.5. Guachetá section (VI & GWI).

Coals from this section have lower values of VI indicating major presence of herbaceous vegetation. Whole seams in Guachetá were deposited in bogs how is shown in the figure 21, and present a good correlation with the Diessel (1986) diagram due the high content of collodetrinite showing major evidences of degradation (Calder et al., 1991) (Singh & Singh, 2000).

The GWI values reflect ombotrophic conditions with a mesotrophic tendency, the hydrology parameter evaluated with this index show shortage of nutrients inhibiting the development of vegetation of greater size. Higher values of this index are presented in 7 Bancos, Suncho Cisquera, Consuelo Superior and Planta de Soda seams corresponding with coals with major content of ash and mineral matter in the Guachetá section as result of the water interaction indicating that rainfalls had a great influence in the nutrients contribution in the peat in the moment when coals were deposited.

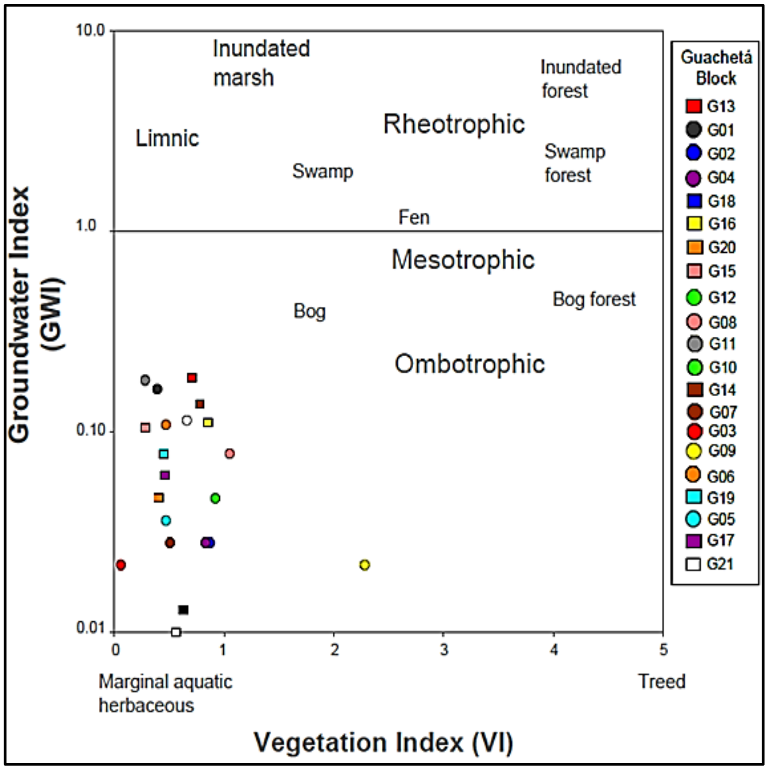

Figure 21. GW/VI mire paleoenvironment diagram of coals of the Guaduas Formation coals, Guachetá section modified from Calder et al. (1991)

5.1.6. Samacá section (VI & GWI).

The figure 22 shows the behavior of coals from Samacá section in the Calder, et al. (1991) diagram. The VI values are below 3 indicating that seams were deposited mainly in bogs according with the kind of present vegetation in the analyzed samples. Higher values of collodetrinite are a symbol of faster degradation and decomposition of the precursor organic matter in the moment of deposition (Diessel, 1986).

The values of GWI are smaller in comparison with the other sections (Sutatausa and Guachetá). The hydrology condition is characterized by ombotrophic processes controlled by rainfalls. The nutrients in this kind of peatbog are reduced and they are rich in acid waters favoring the degradation of the organic constituents; this block presents lower content of ash and mineral matter showing less influence of underground water.

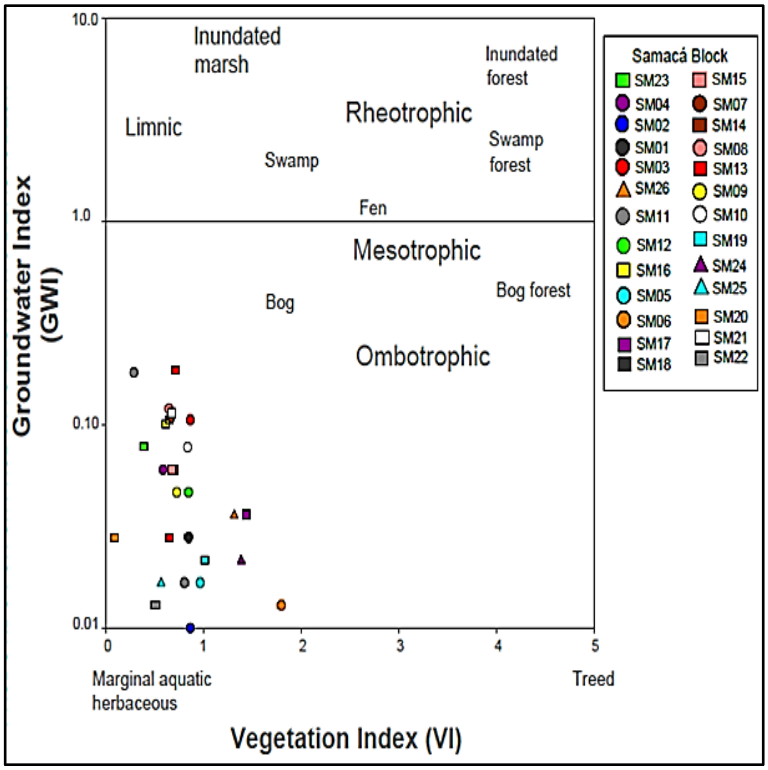

Figure 22. GW/VI mire paleoenvironment diagram of coals of the Guaduas Formation coals, Samacá section modified from Calder et al. (1991)

5.2. TERNARY DIAGRAMS

Different ternary diagrams have been used for authors worldwide to determine specific features of coals in the moment of deposition, for this reason is necessary the aggrupation of macerals constituents of coal and apply a recalculated percent of each one according with the used diagram.

5.2.1. Mukhopadhyay (1986) ternary diagram.

The ternary diagram proposed by Mukhopadhyay (1986) is a schematic representation of the original conditions of peatbogs, it shows the interaction between macerals with good preservation of tissues formed in swamps; macerals more degraded formed in reed mashes and macerals formed in dry conditions (Inertinite group) (Suarez Ruiz & Crelling, 2008) (Mukhopadhyay, 1986) (Singh & Singh, 2000).

The aggrupation of macerals to use this diagram and to realize the recalculate of percentages is presented in the equation 8:

A: Vitrinite (Telinite + Collinite) + terrestrial liptinite

B: Vitrodetrinite + liptodetrinite + Gelocolinite

C: Inertinite

Equation 8. Aggrupation of macerals for each vertex in the Mukhopadhyay ternary diagram.

The position in the ternary diagram for each coal seam can be evidence the following depositional paleoenvironments with its respective features or a transition between someone:

D: Forest swamp, mildly oxic to anoxic with good tissue preservation.

E: Reed marsh, increasing maceration and bacterial activity, increasing anoxic.

F: Dry (Oxic) condition.

The results of this diagram allow identify the original circumstances where coals were deposited. The grouped macerals have similar conditions of formation and can be evidence of predominant vegetation and oxic or anoxic in the peat. Coals from Colombia are enriched in maceral of huminite/vitrinite group showing a high wet in the area of deposition.

Coals from Sutatausa section present a preferential disposition to the D zone (Forest swamp), with good preservation of tissues in anoxic to oxic conditions (Mukhopadhyay, 1986), however is clear like some seams present a light trend to dry- oxic conditions (F zone) and the other ones to Reed marshes (E zone) (Figure 23).

The graphic for Guachetá block (figure 24) shows a more stable behavior in its deposition, coals from here were deposited in forest swamps (D zone) with a oxic trend (F zone) indicating that the maceration and bacterial activity in this area are lower in comparison with the Sutatausa block.

The Samacá section has a stable behavior too. Coals in this area were deposited in forest swamps (D zone); they have good preservation of tissues and they present an oxic trend (F zone) according with the inertinite content. The "Tercera (La ligada)" seam is the only coal from this block with a reed marsh environment tendency (Figure 25).

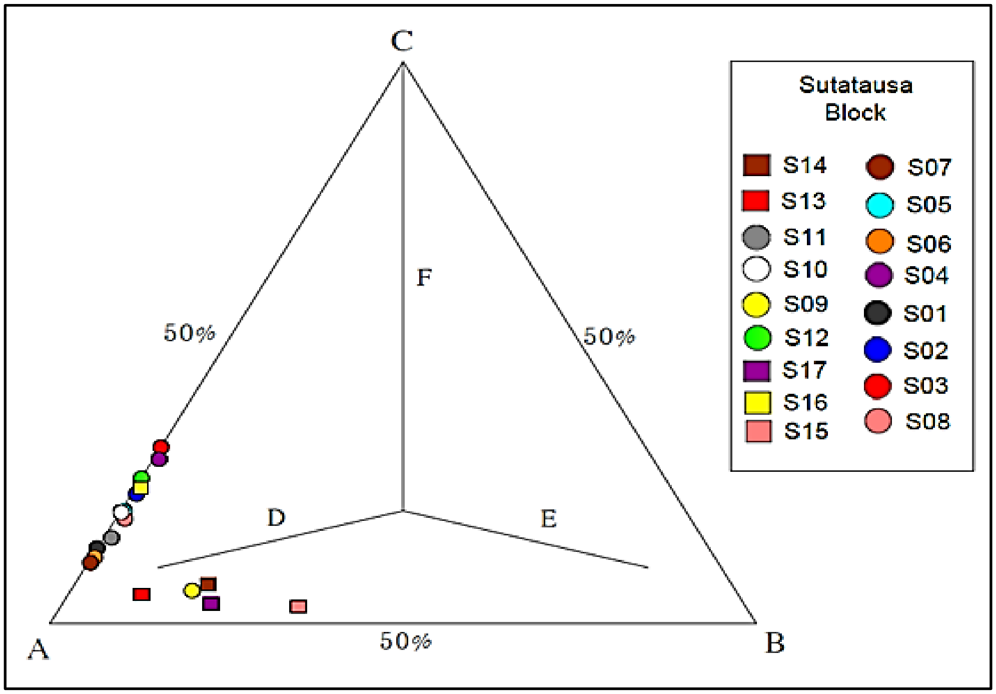

Figure 23. Ternary diagram illustrating facies–critical maceral association in coals and suggested peat environments – Sutatausa section- (Modified from (Mukhopadhyay, 1986) and (Singh & Singh, 2000))

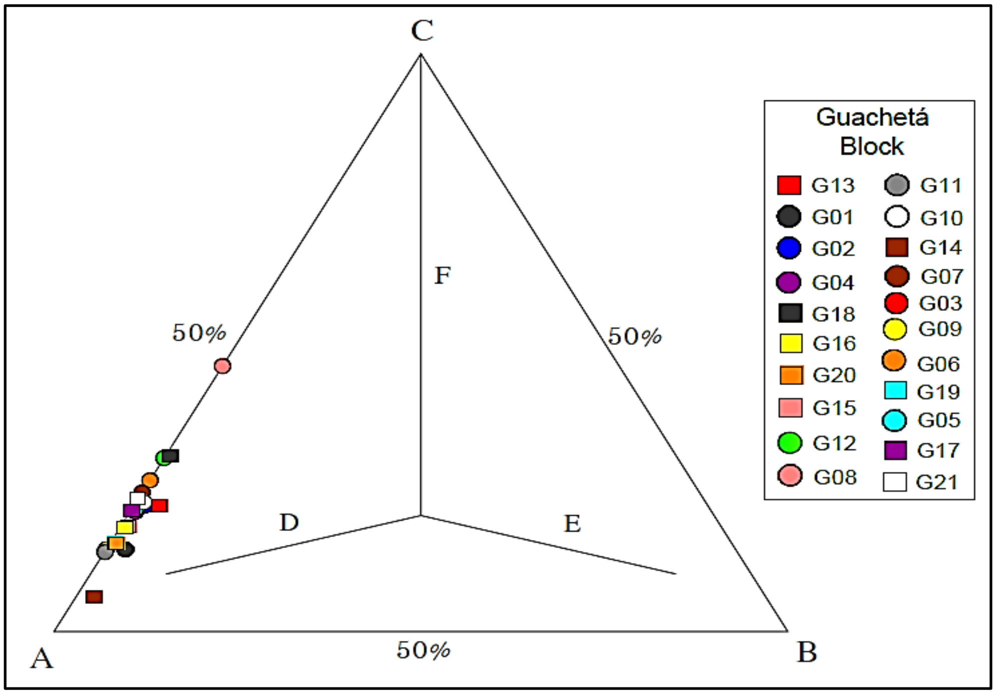

Figure 24. Ternary diagram illustrating facies–critical maceral association in coals and suggested peat environments – Guachetá section- (Modified from (Mukhopadhyay, 1986) and (Singh & Singh, 2000))

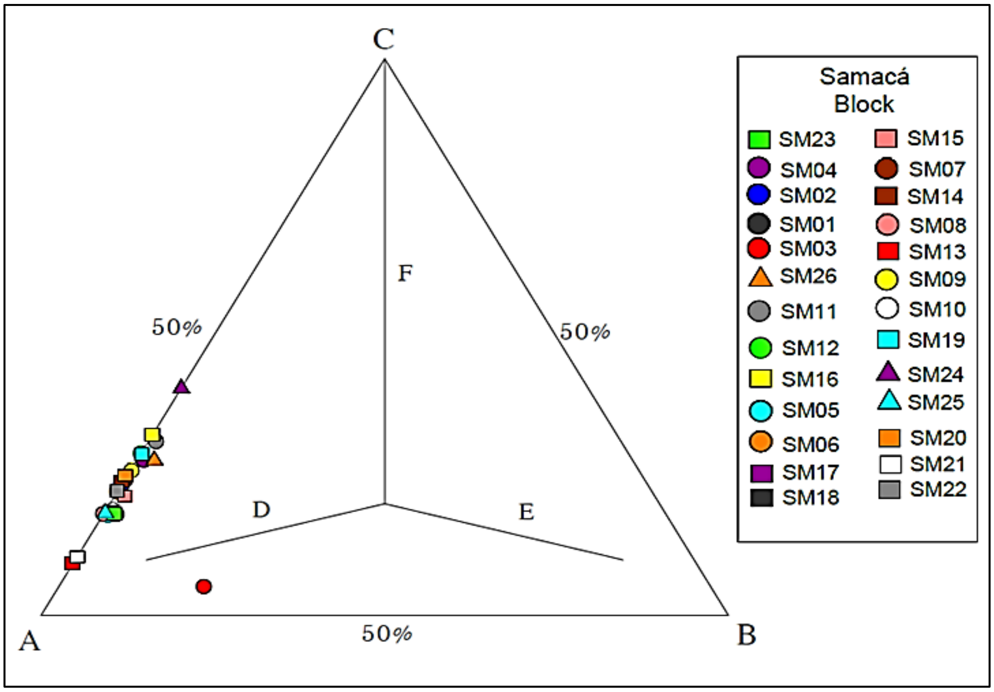

Figure 25. Ternary diagram illustrating facies–critical maceral association in coals and suggested peat environments –Samacá section- (Modified from (Mukhopadhyay, 1986) and (Singh & Singh, 2000))

5.2.2. Singh and Singh (1996) ternary diagram.

This ternary diagram is a modification from Goodarzi (1985) for the Hat Creek coals in the United States of America realized by Singh & Singh (1996) to determine the importance of mineral matter in the depositional environment and its influx in the water surface in the Rajmahal basin, Bihar, India. The model allows the interpretation of wet and dry conditions and their relation with the subsidence ratio (Singh & Singh, 1996).

The position in the ternary diagram can indicate the following results:

D: Alternate oxic and anoxic moor.

E: Oxic (Dry) moor with sudden high flooding.

F: Wet moor with intermittent moderate to high flooding.

The results from this facies model indicate a preferential deposition in an environment with alternation of oxic and anoxic moors (Figures 26, 27 and 28) as result of changes in the sea level and its eustatic subsidence (Singh & Singh, 2000). The behavior of maceral aggrupation to use this diagram in the three sections is similar, the coal samples present higher values of vitrinite and liptinite indicating good conservation of the precursor organic matter and protection against oxidizing conditions, the content of inertinite is related with oxic processes as sub area exposure and forests fires; and the content of mineral matter is related with flood processes which they are evidenced in the content of framboidal pyrite that also suggests the development of intermittent brackish water conditions as product of marine incursions (Singh & Singh, 1996). This conclusion is according with the results of Diessel (1986) and Calder, et al. (1991) diagrams where coals were affected by stronger degradation and a good water flow enriched the seams in the ash and mineral matter content.

The three sections of the Checua-Lenguazaque syncline present the same conditions in this model (D zone position); however the Planta de Soda and Suncho Cisquera seams in the Guachetá section (Figure 27) and the Tesoro seam in the Samacá section (Figure 28) were deposited in wet moors with greater influx of flooding due the content of mineral matter. The features of deposition and the variation in the condition (Oxic, anoxic and flooded) can be related with occurred tectonic events in the basin modifying the environments of formation as Singh & Singh (2000) proposed in the Indian coals.

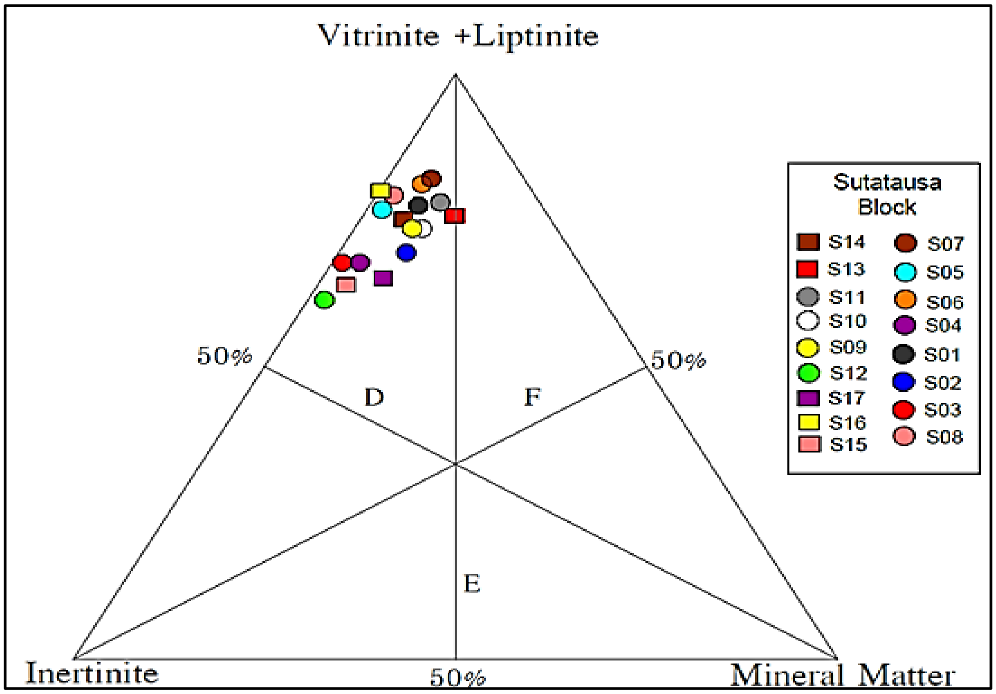

Figure 26. Depositional condition of the coals of Sutatausa section based on maceral and mineral matter (Modified from (Singh & Singh, 1996)).

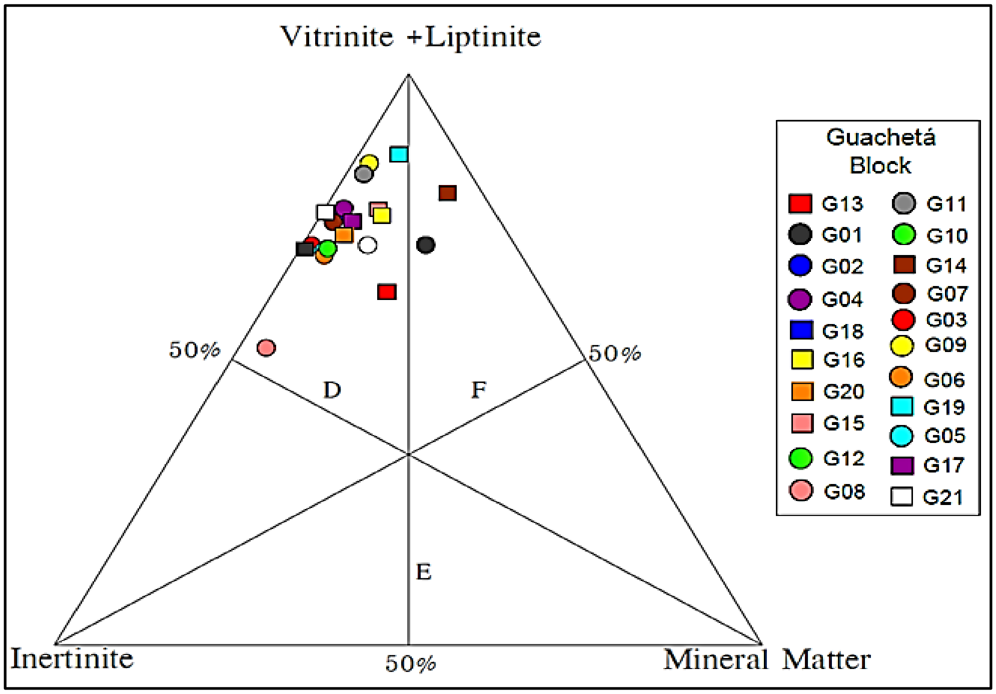

Figure 27. Depositional condition of the coals of Guachetá section based on maceral and mineral matter (Modified from (Singh & Singh, 1996)).

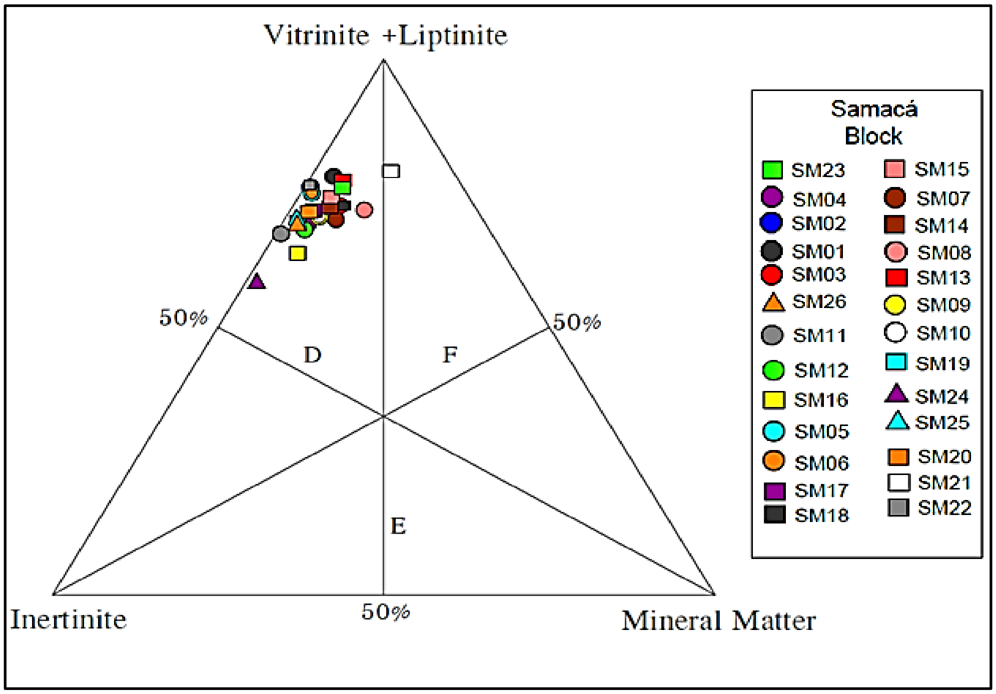

Figure 28. Depositional condition of the coals of Samacá section based on maceral and mineral matter (Modified from (Singh & Singh, 1996)).

5.2.3. Singh and Singh (2000) ternary diagram (Association of macerals of the liptinite group).

This ternary diagram is used to interpreting the water depth conditions and the type of coal facies (Singh & Singh, 2000). The model is based in the occurrence of macerals of the liptinite group and it gives an idea of the type of coal (Humic or sapropellic coal) and the type of vegetation in the area in the moment of deposition.

The diagram can show the following results:

A: Area for development of algal bloom and the zone of anaerobic bacterial activity.

B: Open water swamp dominated by reed plants.

C: Transition between forest swamp and reed swamp.

The Colombian coals of Guaduas Formation (Upper Cretaceous to Paleocene) are classified as humic coals due the presence of terrestrial lithotypes and the maceral composition, indicating that seams are enriched in organic remains of terrestrial origin with low content of marine plant remains (Guatame & Sarmiento, 2004) (Mejía Umaña et al., 2006).

Any coal in the three sections was deposited in areas for development of algal bloom with only anaerobic bacterial activity (A zone); conversely the coal seams were deposited in open water swamps dominated by reed plants (B zone) and in a transition between forest swamps and reed swamps (C zone). The samples presented a predominance of cutinite and resinite in this maceral group showing the variation of water depth in the peatbog with rapid transitions between forests and reed swamps (Singh & Singh, 2000).

The results from Sutatausa section is presented in the figure 29, here is clear the tendency to a reed swamps with a higher water depth but not enough for development of alginite. The figure 30 shows the results for the Guachetá block, where there is greater dispersion of data suggesting a stronger variation in the phreatic level and its implication in the kind of vegetation in the moment of deposition. The Samacá section presents a trend to reed swamps (B zone) as is evident in the figure 31; however the depositional conditions are very similar to the Guachetá section presenting a good correlation with the other diagrams utilized in the investigation.

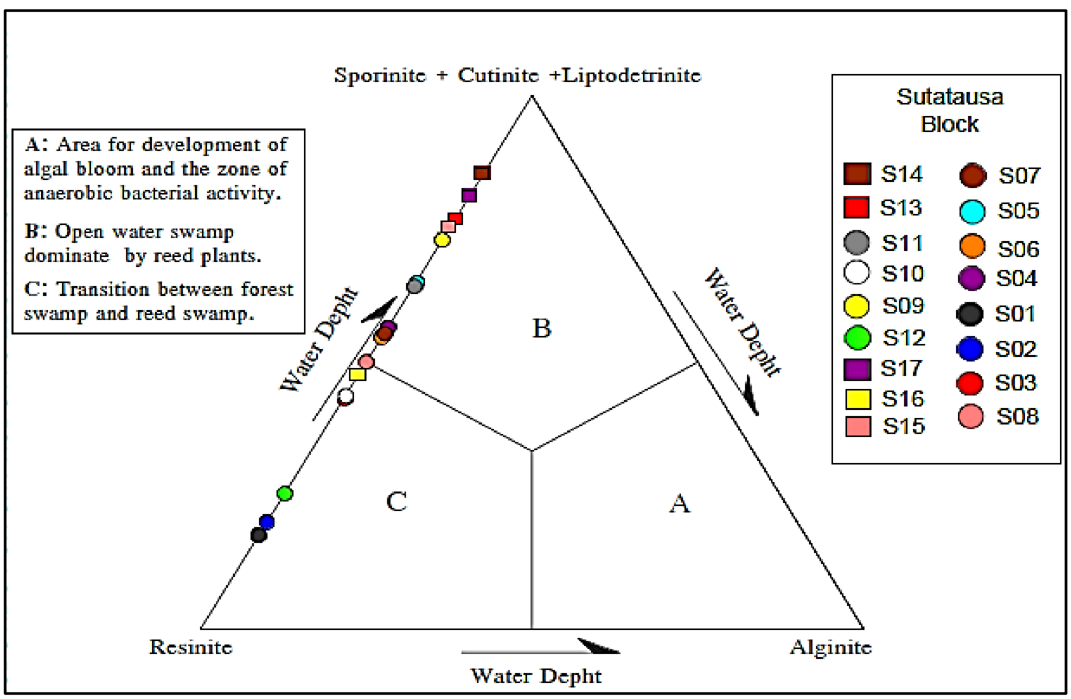

Figure 29. Type of coal facies and water depth conditions based on quantitative occurrence of liptinite macerals, Sutatausa section (Modified (Singh & Singh, 2000)).

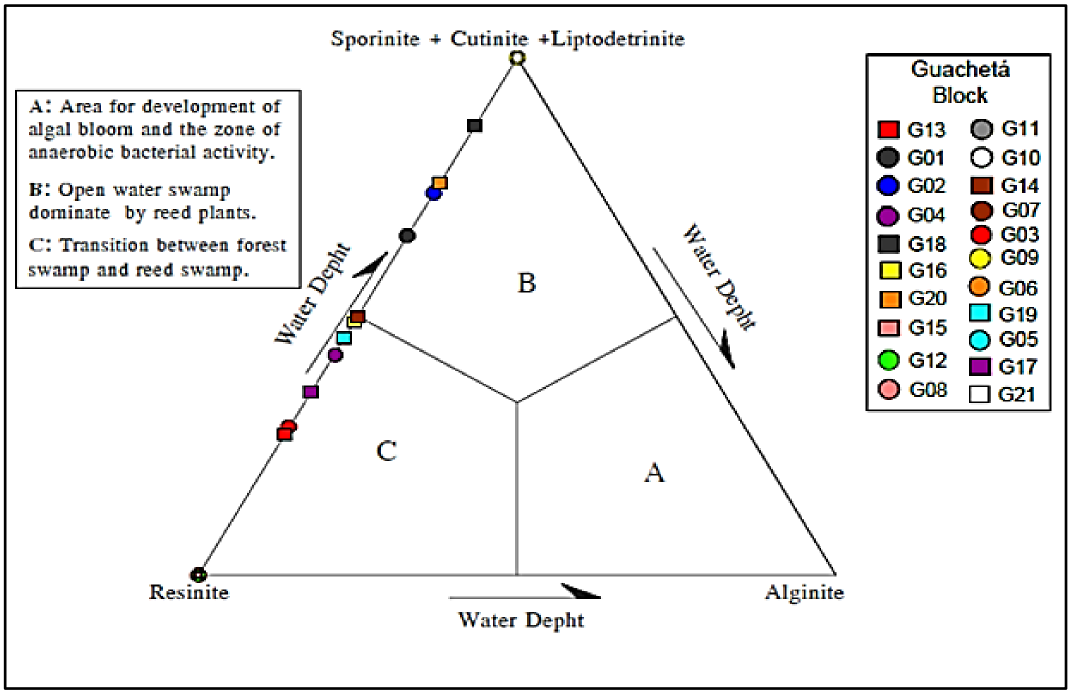

Figure 30. Type of coal facies and water depth conditions based on quantitative occurrence of liptinite macerals, Guachetá section (Modified (Singh & Singh, 2000)).

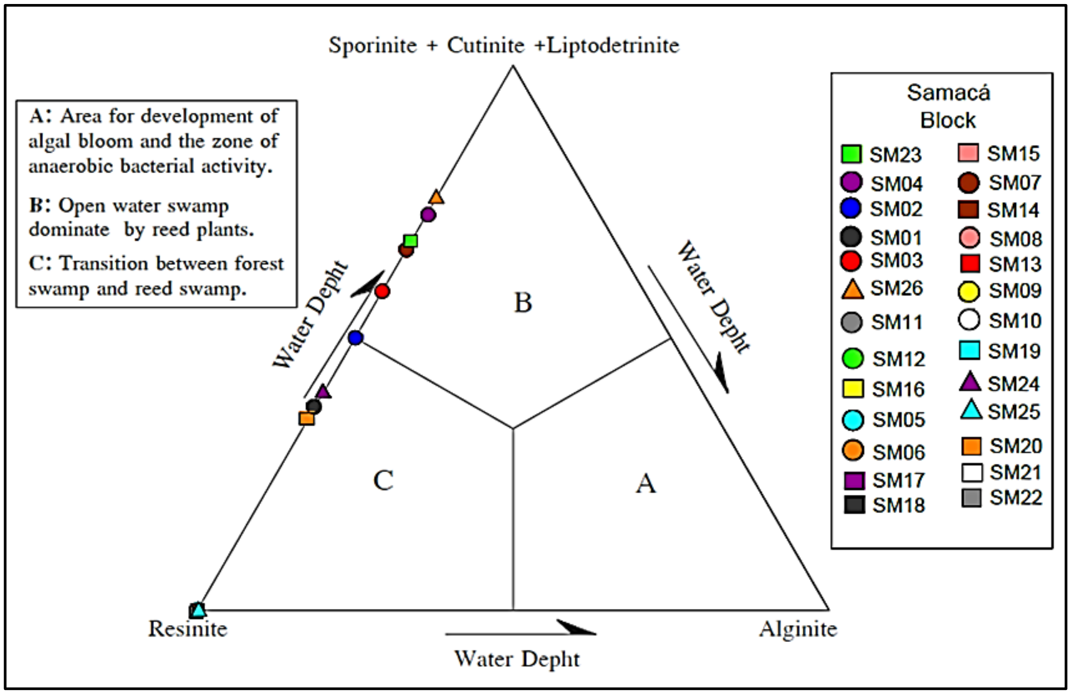

Figure 31. Type of coal facies and water depth conditions based on quantitative occurrence of liptinite macerals, Samacá section (Modified (Singh & Singh, 2000)).

6. CHAPTER SIX: PROPERTIES OF COAL AND PALEO-ENVIRONMENTAL RELATIONSHIP - DISCUSSION

The physicochemical properties in a coal can be directly related with the depositional environment as sulfur and ash content while others are related with the coalification (Vessey & Bustin, 2000). The different acquired diagrams with the organic petrography give an idea of the paleoenvironment and its influence in the quality of coal.

6.1. ASH CONTENT

The found ash in the studied coals is mainly clay, quartz, sulfur and ferrous minerals; so the coals with percentages of ash up 10.00% were deposited in marshes and back barrier zones showing the importance of the marine incursions and floods in the mineral matter content during the deposition of the peatbog. The coals deposited in marshes presented more of 8.0% in ash with predominance of clay minerals and quartz. The seams with the higher content of ash were the Deposito and La Grande 2 (23.14% and 25.09%) in the Sutatausa section; both coals were deposited in the stratigraphic column after a sandstone deposit product of flood plains in coastal zones, the proximity to a river channel can be the source of the clastic sediments in these coals, in the same way they have the mesotrophic trend indicating more quantity of nutrients.

In the Guachetá section the seams with the higher content of ash were Suncho Cisquera, 7 Bancos and Planta de Soda (15.35%, 16.77% and 13.42%), these coals were deposited above of a flood event marked by a sandstone deposition in the stratigraphic column, but in the study area the 7 Bancos seams is known for presenting some intercalations that in the maceral composition are seen as clay minerals; in Samacá, this seam presents the higher content of ash too in the stratigraphic column (12.73%) allowing the correlation of this carboniferous horizon but with an increase in the size grain due the quarts content. The relationship between ash and sulfur content is not clear due the sulfur in some seams is organic. It is evident like open water swamps have a high content of ash too although the tendency is not clear.

6.2. SULFUR CONTENT

The sulfur content in the coal samples was of two types, organic and inorganic, the predominant environment with high content of sulfur were the back barrier zones followed by marshes. The low sulfur content of the Guaduas Formation coals indicates only that they were not subjected to long-term inundation by marine waters (Vessey & Bustin, 2000). In the Sutatausa section the higher contents of sulfur were found in the Deposito and 7 Bancos seams (1.61% and 1.48%), these coals were deposited in a transition of intermareal and supramareal flats affirming the importance of marine incursions. In the Guachetá section the coals with higher content of sulfur were Suncho Cisquera and Veta Grande seams (1.85% and 1.36%) deposited in marshes. In Samacá the coals with higher sulfur contents were La Tercera and 7 Bancos (1.55% and 1.82%) which were deposited in back barrier zones.

6.3. PROPERTY PROFILES

The major properties of coals were graphed in the figures 32, 33,34,35,36, and 37 for the three section of the Checua-Lenguazaque syncline. The profiles showed an abrupt change in the interval of 250 - 300 m, for the Sutatausa section there is an increase of moisture, ash, sulfur, mineral matter and macerals of the inertinite group (Figures 32 and 33), the coals from this interval present good quality according with the rank and reflectance of vitrinite but they have a high content of ash and sulfur. In the Guachetá section the moisture, ash, and mineral matter increase but the sulfur content is lower along the profile and there is a gradual increase of macerals of the inertinite group from base to top (Figures 34 and 35). In Samacá there is a similar behavior but the increase is more evident in the content of macerals of the inertinite group (Figure 37), but the increase more significant of sulfur is present in the top of the column how is shown in the figure 36.

LEGEND

M: Moisture **A:** Ash **VM:** Volatile matter **FC:** Fixed carbon **S (Db):** Sulfur (Dry basis)

V: Vitrinite **L:** Liptinite **I:** Inertinite **MM:** Mineral matter

6.3.1. Sutatausa section.

The properties in the Sutatausa section varied along of their position in the stratigraphic column. Sulfur content increase progressively after 350 m (Up to 1.40%). The higher value of ash is present in the 330 m where there is an increase of moisture and volatile matter indicating changes in the carbonification process in this sector.

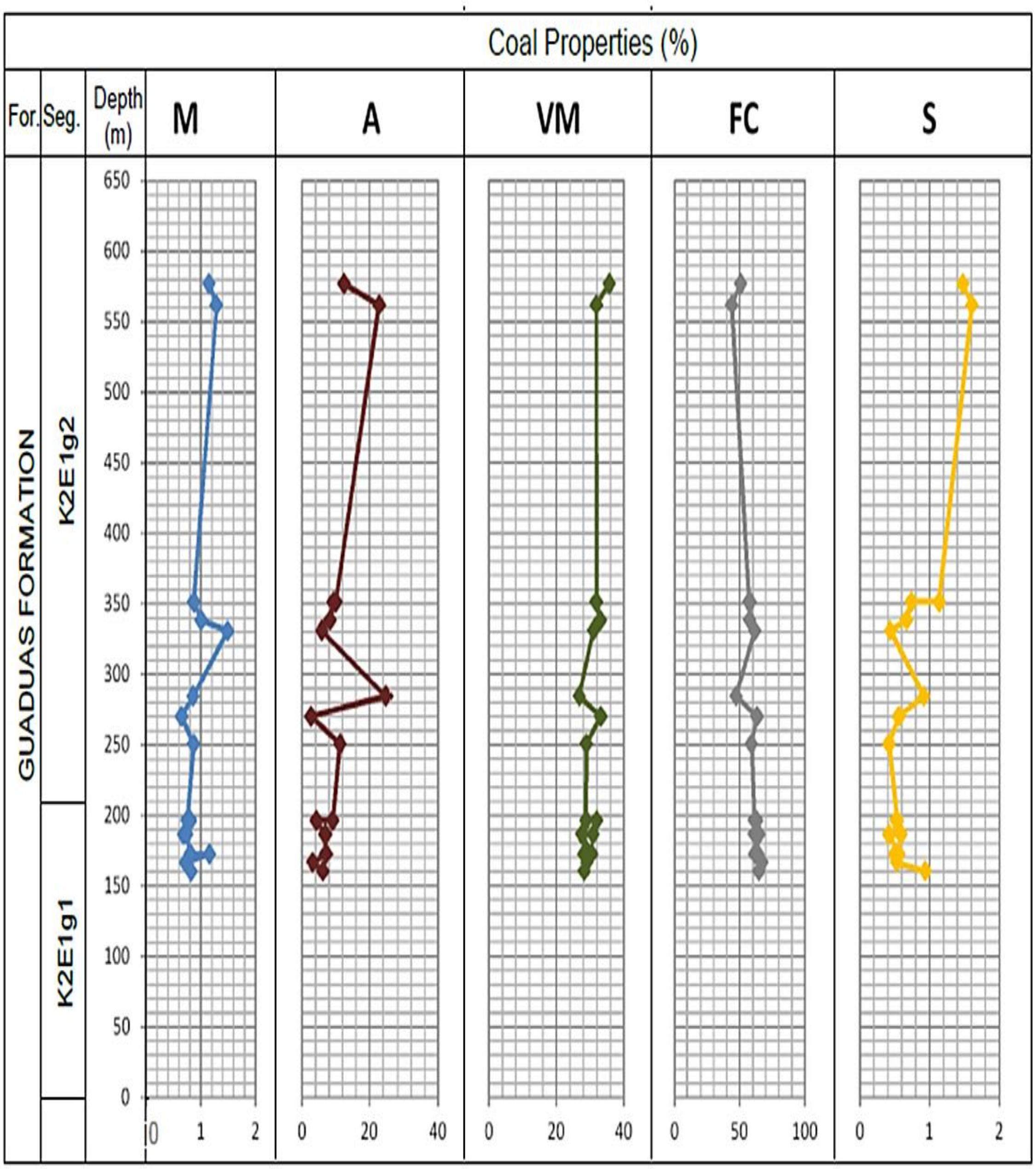

Figure 32. Profile of properties of coal in the Sutatausa section (Y axis: Depth (m), X axis: %).

The vitrinite content in Sutatausa is higher in the base of the column while the content of liptinite is lower; the content of inertinite varies in the profile evidencing stages of oxidation of the organic matter and possible changes in the water surface in the peat bog. The mineral matter has a peak in the 280 m suggesting an inundation with a high content of detrital materials (Figure 33).

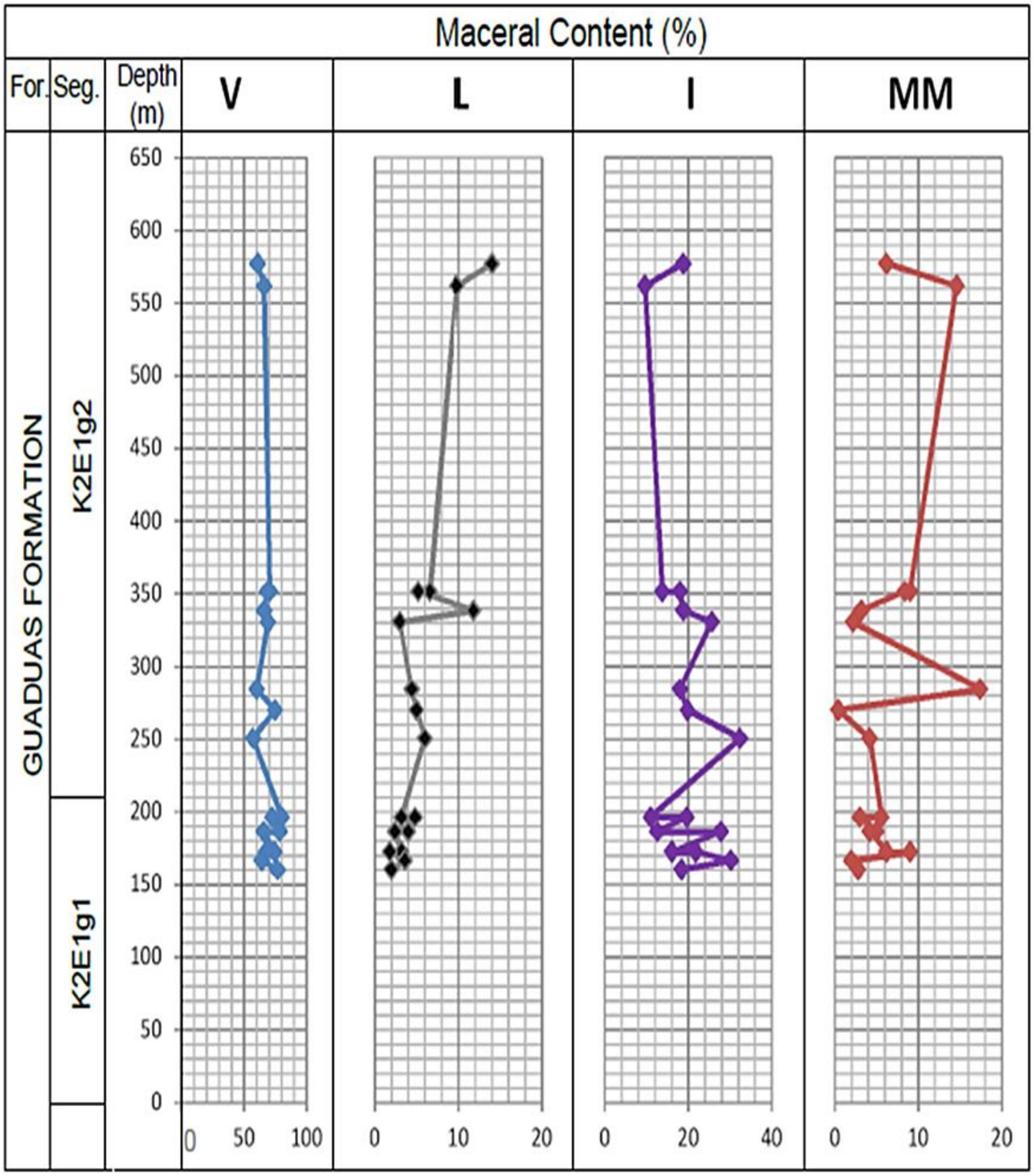

Figure 33. Profile of maceral reading in the Sutatausa section (Y axis: Depth (m), X axis: %).

6.3.2. Guachetá section.

The properties in the Guachetá section showed a more disperse data. The moisture has a decrease in the interval 250-350m coinciding with an increase of ash. The sulfur content is higher in the top of the Column with values close to 1.00% in the 7 Bancos and Deposito seams which it is in relation with the intercalations of clastic materials (Figure 34).

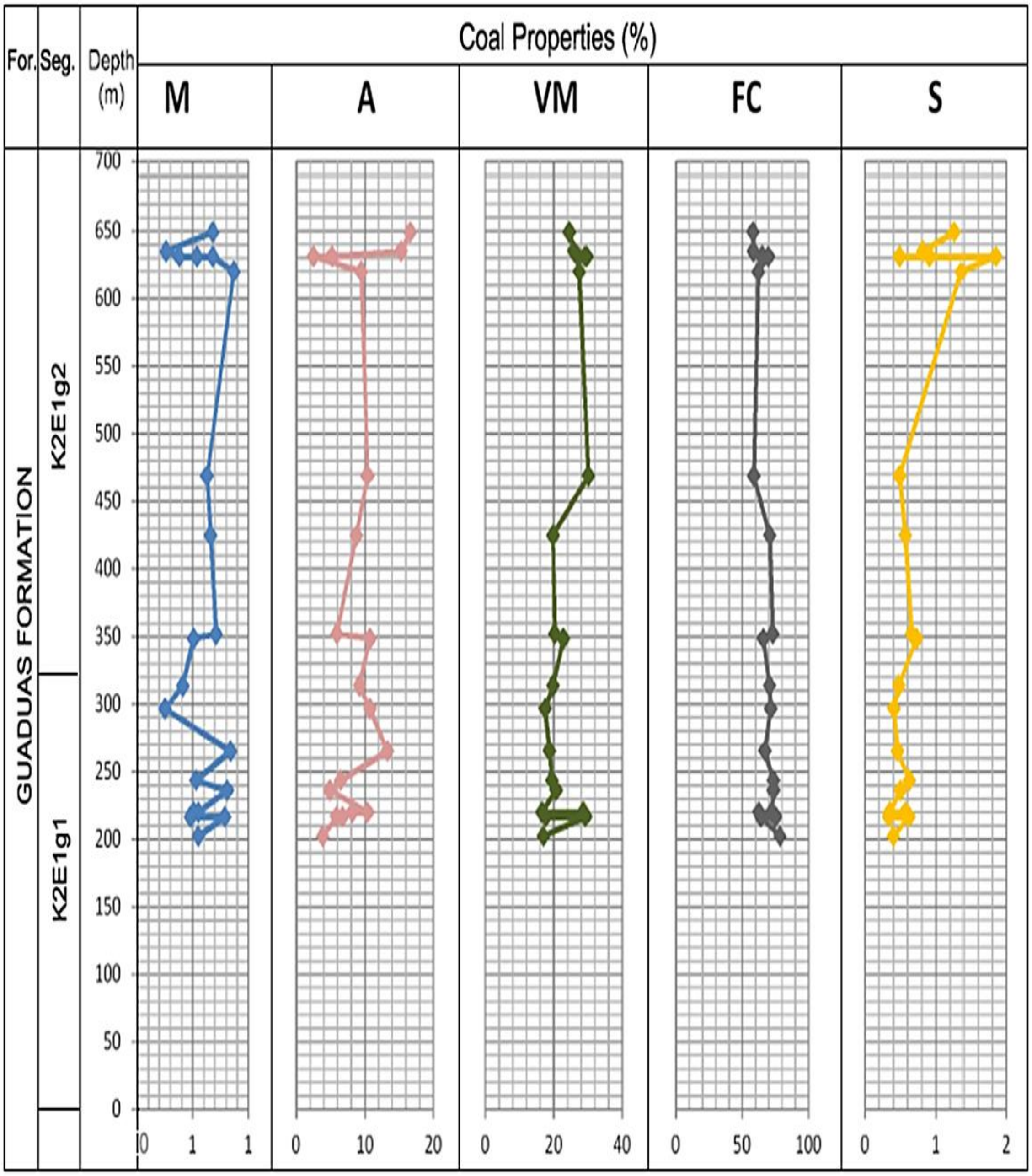

Figure 34. Profile of properties of coal in the Guachetá section (Y axis: Depth (m), X axis: %).

The vitrinite content in the Guachetá section decreases gradually in the stratigraphic column from base to top. There is an increase of liptinite from the 470 m. Here the fluctuant content on inertinite evidences the variation of the water surface and oxidizing processes. The mineral matter is higher in the 250 – 300m interval (Figure 35)

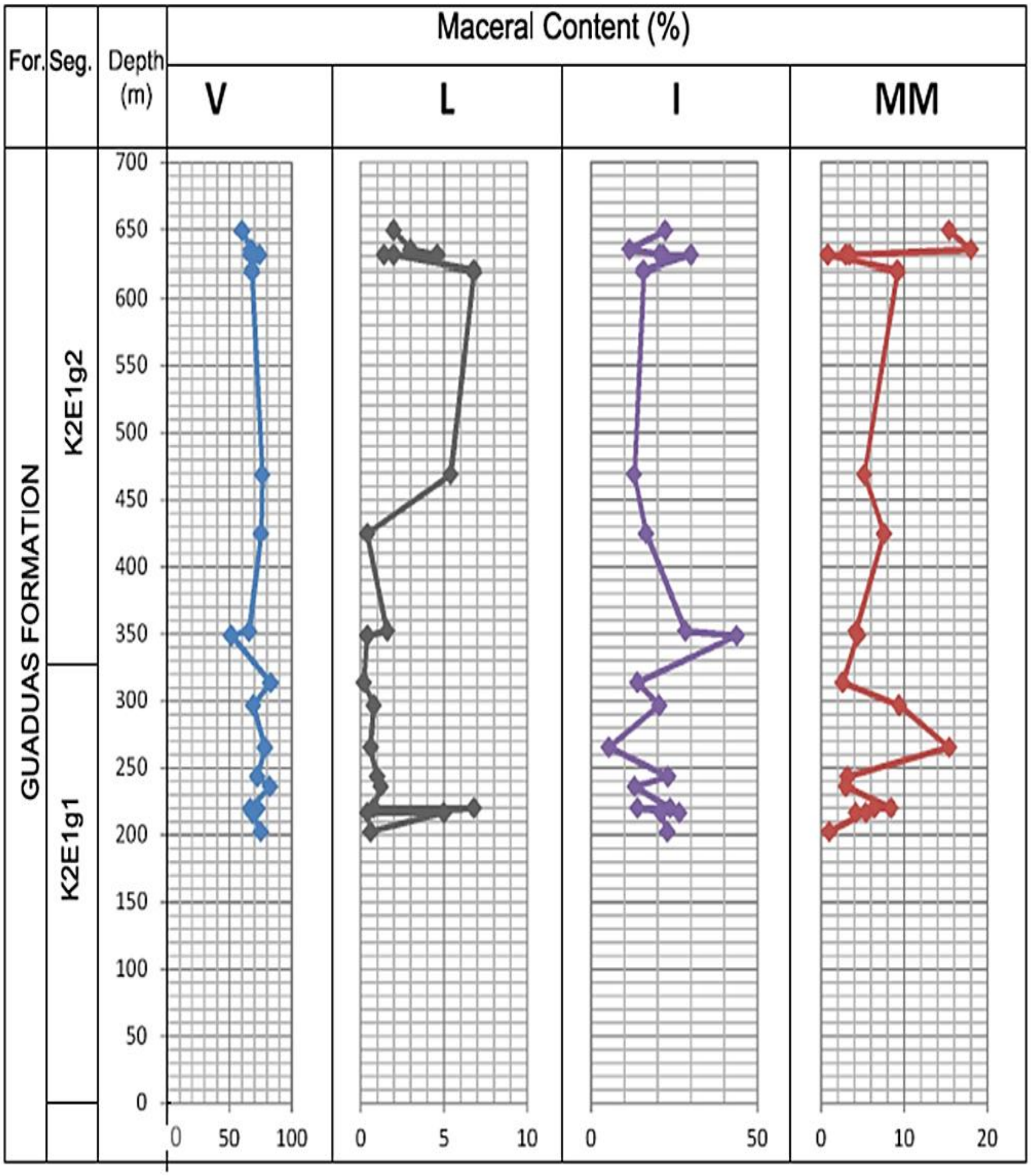

Figure 35. Profile of maceral reading in the Guachetá section (Y axis: Depth (m), X axis: %).

6.3.3. Samacá section

In Samacá, the higher content of moisture, ash and sulfur are present up 515 m, so for the same coal seams there are different values of ash in the interval 250-300 m. the volatile matter has a normal behavior according with depth how is shown in the figure 36.

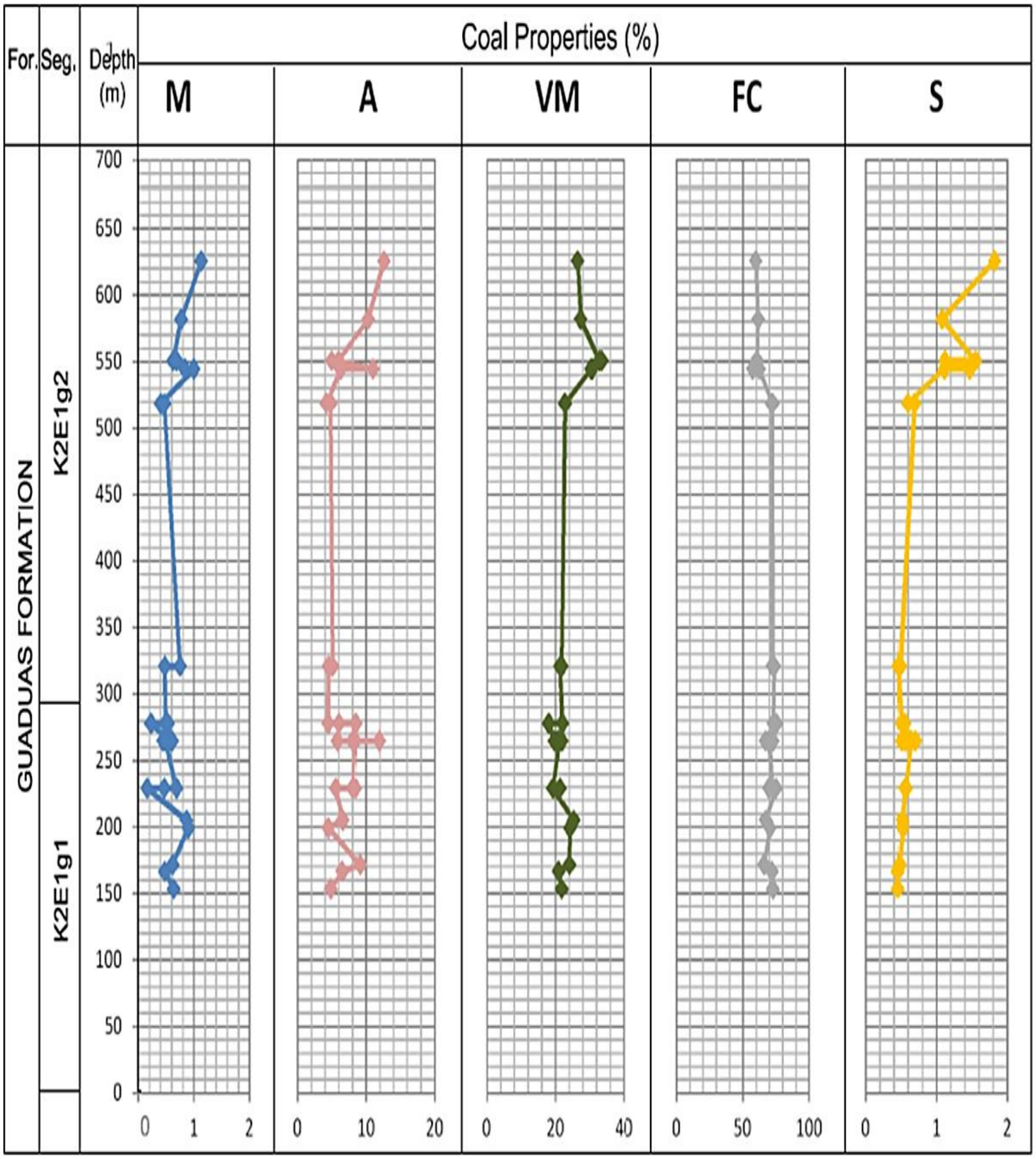

Figure 36. Profile of properties of coal, Samacá section (Y axis: Depth (m), X axis: %).

The vitrinite content in the Samacá section decreases gradually in the stratigraphic column from base to top. The liptinite content is little but there is a peak in the 540 m. The content of inertinite is variable but is higher than in the other two sections (Figure 37).

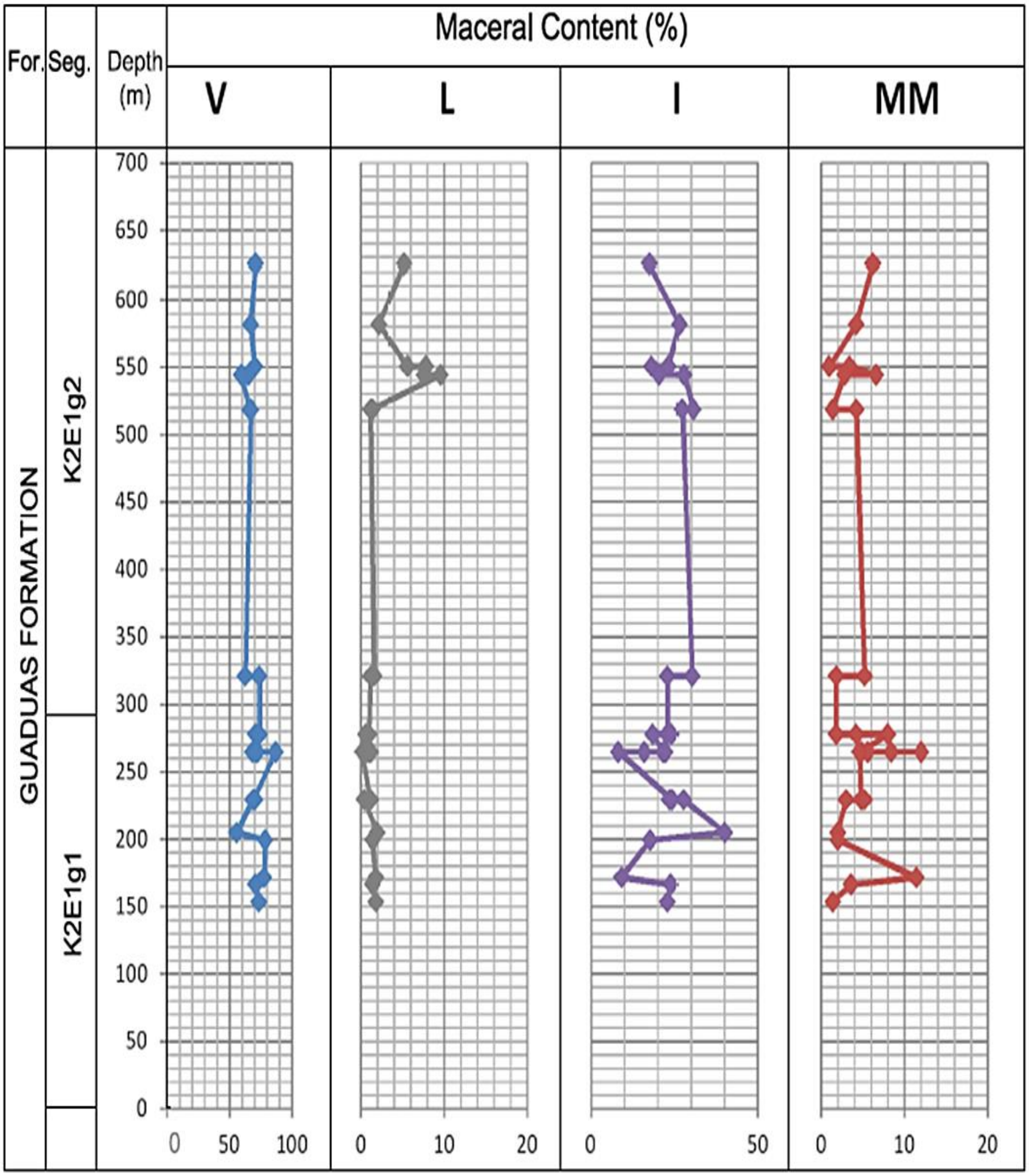

Figure 37. Profile of maceral reading in the Samacá section (Y axis: Depth (m), X axis: %).

6.4. ANALYSIS AND CORRELATIONS

The results of the environment and the properties derived are shown in the tables 16, 17 and 18 for the Sutatausa, Guachetá and Samacá sections respectively, the boxes marked in red are the coals with the next features:

Ash: >10%
Sulfur: >0.9%
Organic pyrite: >0.6%
Inorganic pyrite: > 0.2%

Clay minerals: > 3%
Ferrous minerals: > 0.4%
Quarts: >1.5%

6.4.1. Ash.

Although coals are the best known kind of carbonaceous sediment, they are composed predominantly of combustible organic matter but contain various amounts of impurities (ash), which are largely siliciclastic materials (Boggs, 2006). Then, in the studied seams, the higher content of ash was present in coals deposited in back barrier zones and marshes, or in a transition between some of these environments. The results are presented in the figure 38. However in Sutatausa there are high contents in wet forests swamps.

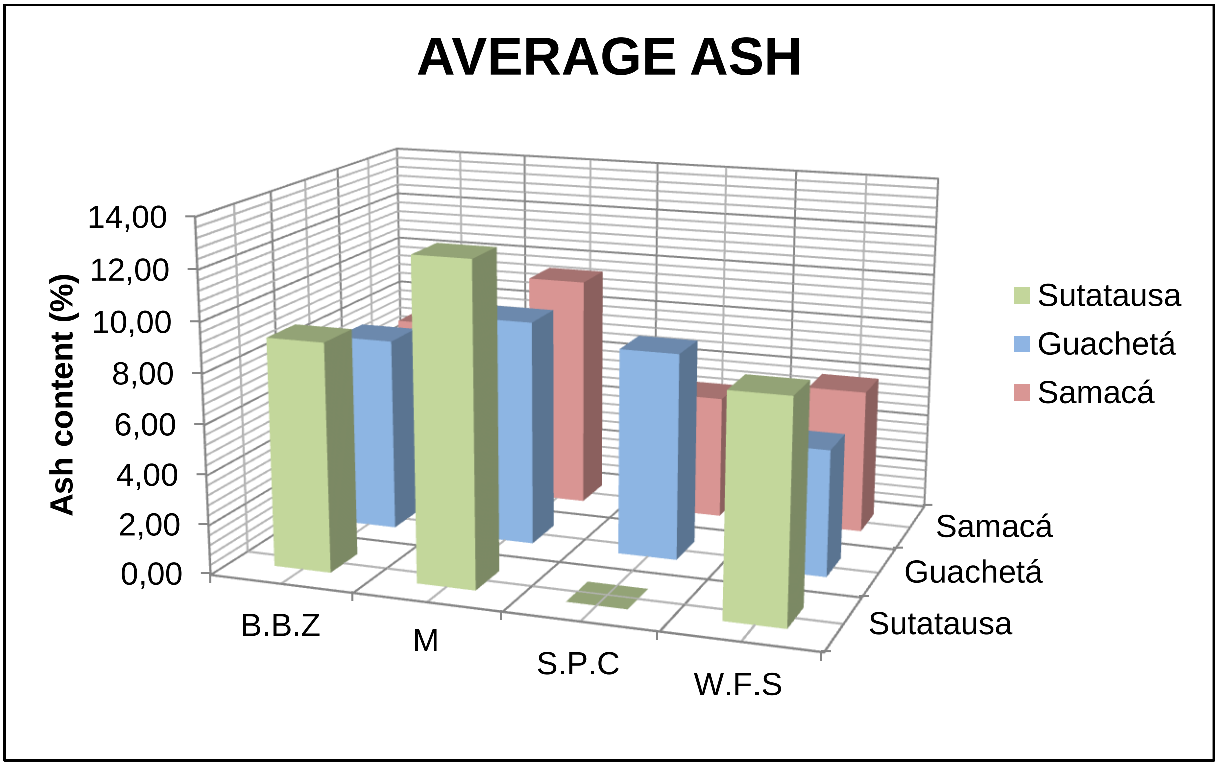

Figure 38. Ash content in the three sections.

6.4.2. Sulfur.

The higher content of sulfur is present in environments as marshes and back barrier zones. The lower content is present in the Guachetá section how is shown in the figure 39 but in the wet forest swamps the content is similar in the three sections.

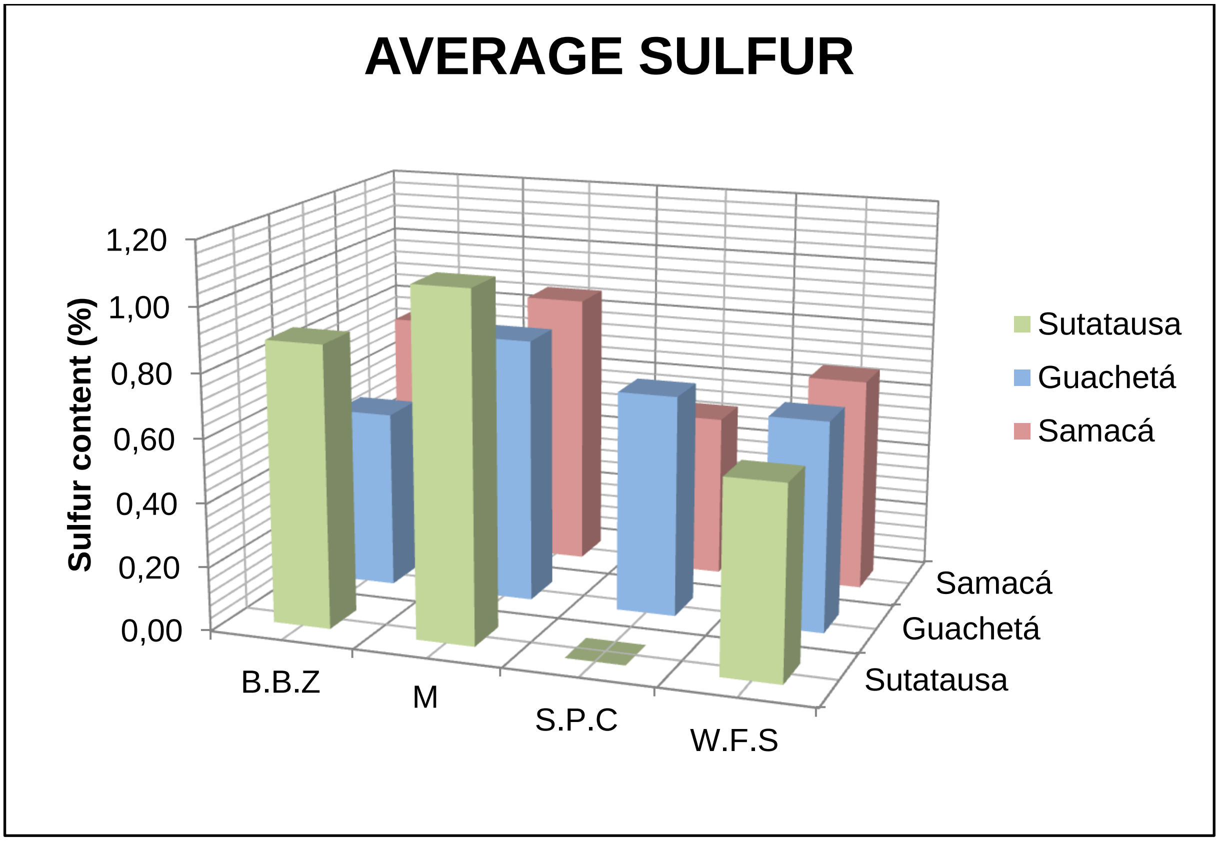

Figure 39. Sulfur content in the three sections.

The relation between ash and sulfur content is not clear, when there is a relationship between both properties is an evidence of content of inorganic pyrite but when ash content does not significantly correlate with sulfur content suggesting that most of the sulfur is organic (Vessey & Bustin, 2000). The results are shown in the figure 40 having the data from the Samacá section the best correlation. The data from the Sutatausa section have the worst correlation which is related with the obtained results from the petrographic test. The coals with high sulfur content in this study have more influence of marine or brackish water during peat deposition and compaction (Horne, 1978).

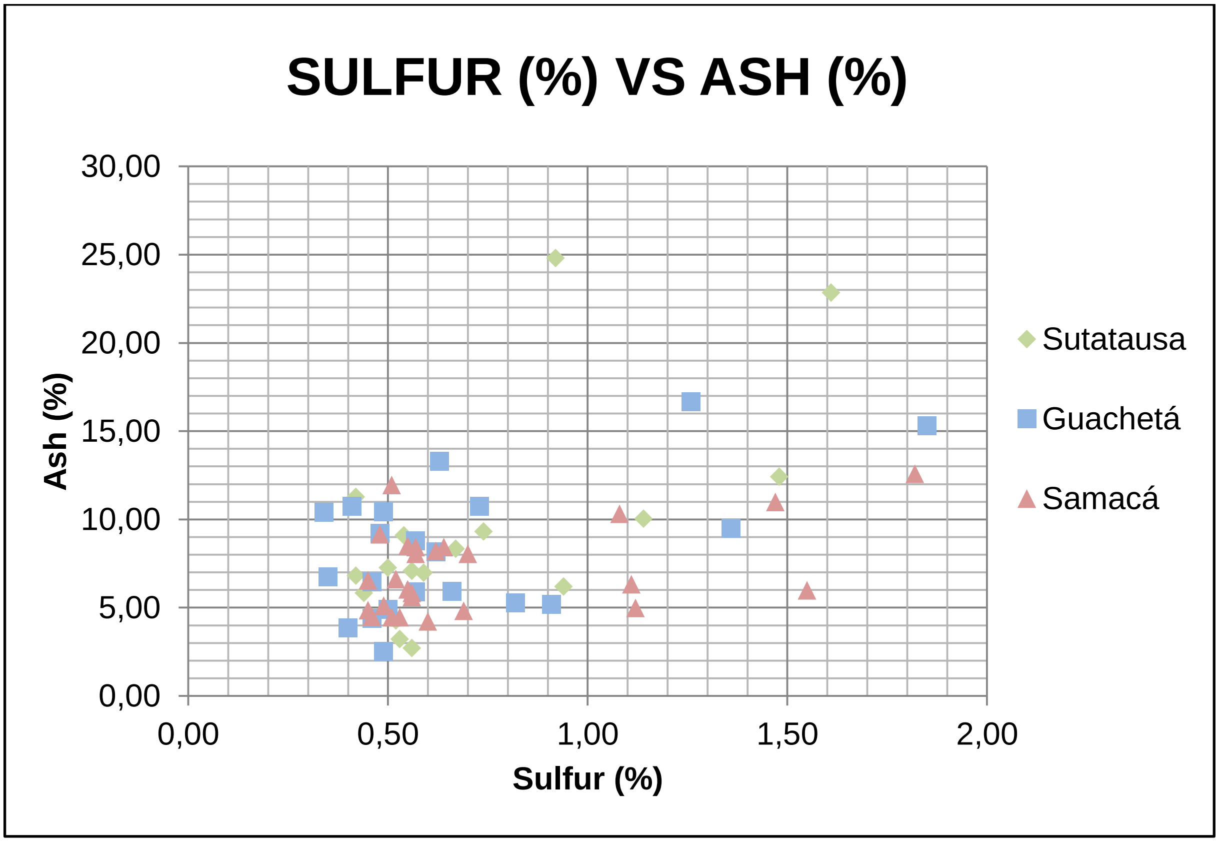

Figure 40. Correlation between ash and sulfur contents.

LEGEND

BBZ: Back barrier zones
M: Marsh
SPC: Strand plain coal
WTF: Wet forest swamp

Table 16.

Coal samples with depositional environments and properties (Sutatausa section).

SAMPLES		DIAGRAMS					FEATURES							
CODE	SEAM	Diessel (1986)	Calder et al. (1991)	Mukhopadhyay (1986)	Singh and Singh (1996)	Singh and Singh (2000)	THICKNESS	ASH	SULFUR	O. PYRITE	I. PYRITE	CLAY MINERALS	FERROUS MINERALS	QUARTZ
S14	7 BANCOS SUPERIOR	B.B.Z - M	O.B	F.S - R.M	D	O.W.S.D.b.R.P	2,34	12,43	1,48	0,60	0,20	4,40	0,00	1,00
S13	DEPOSITO	M	O.B - M.B	F.S - R.M	D - F	O.W.S.D.b.R.P	0,83	22,84	1,61	0,40	1,20	11,80	0,00	1,20
S11	VETA PRIMERA	B.B.Z - M	O.B	F.S	D	T.B.F.S.a. R.S	1,18	10,04	1,14	0,40	0,00	7,60	0,00	1,00
S10	CISCUDA	W.F.S - M	O.B	F.S	D	T.B.F.S.a. R.S	1,7	9,32	0,74	0,60	0,20	6,60	0,00	1,00
S09	CHICA 3	W.F.S - M	O.B	F.S - R.M	D	O.W.S.D.b.R.P	1,02	8,34	0,67	0,20	0,00	2,40	0,20	0,40
S12	QUINTAS	B.B.Z - W.F.S	O.B	F.S	D	T.B.F.S.a. R.S	1,7	5,84	0,44	0,00	0,00	1,80	0,20	0,20
S17	GRANDE 2	W.F.S - M	O.B - M.B	F.S - R.M	D	O.W.S.D.b.R.P	1,37	24,80	0,92	1,60	0,40	5,60	8,00	1,80
S16	CHICA 2	M	O.B	F.S	D	T.B.F.S.a. R.S	0,78	2,72	0,56	0,00	0,00	0,00	0,20	0,20
S15	7 BANCOS INFERIOR	B.B.Z	O.B	F.S - R.M	D	O.W.S.D.b.R.P	1,35	11,27	0,42	0,00	0,00	4,00	0,00	0,20
S07	GEMELA SUPERIOR	W.F.S	O.B	F.S	D	O.W.S.D.b.R.P	0,3	9,11	0,54	0,00	0,00	4,40	0,40	0,80
S05	GEMELA SUPERIOR	W.F.S	O.B	F.S	D	T.B.F.S.a. R.S -O.W.S.D.b.R.P	0,8	4,28	0,52	0,00	0,00	1,20	0,00	1,80
S06	GEMELA INFERIOR	W.F.S	O.B	F.S	D	T.B.F.S.a. R.S -O.W.S.D.b.R.P	0,7	6,98	0,59	0,00	0,00	3,80	0,00	1,20
S04	GEMELA INFERIOR	W.F.S	O.B	F.S	D	T.B.F.S.a. R.S	0,9	6,82	0,42	0,20	0,00	1,80	0,00	2,20
S01	LA GRANDE 1	W.F.S	O.B (> 2 GI)	F.S	D	T.B.F.S.a. R.S	1,4	7,08	0,56	0,00	0,00	4,20	0,20	1,80
S02	LA GRANDE 1	W.F.S	O.B (> 2 GI)	F.S	D	O.W.S.D.b.R.P	1,35	7,26	0,50	0,20	0,00	6,60	0,00	2,20
S03	CHICA 1	W.F.S	O.B	F.S	D	T.B.F.S.a. R.S	1,02	3,22	0,53	0,00	0,00	1,20	0,00	0,80
S08	VETA PRIMERA	B.B.Z - M	O.B	F.S	D	T.B.F.S.a. R.S	0,5	6,20	0,94	0,20	0,00	1,80	0,00	0,80

Table 17.

Coal samples with depositional environments and properties (Guachetá section).

SAMPLES		DIAGRAMS					FEATURES							
CODE	SEAM	Diessel (1986)	Calder et al. (1991)	Mukhopadhyay (1986)	Singh and Singh (1996)	Singh and Singh (2000)	THICKNESS	ASH	SULFUR	O. PYRITE	I. PYRITE	CLAY MINERALS	FERROUS MINERALS	QUARTZ
G13	7 BANCOS	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	2,35	16,66	1,26	0,20	0,80	11,80	0,40	2,20
G01	SUNCHO CISQUERA	M	O.B	F.S	F	O.W.S.D.b.R.P	0,41	15,31	1,85	0,80	1,00	10,40	0,40	5,40
G02	CISQUERA NIVEL 80	M - W.F.S	O.B	F.S	D	O.W.S.D.b.R.P	1,05	5,27	0,82	0,00	0,00	2,00	0,00	1,00
G04	CISQUERA NIVEL 180	M	O.B	F.S	D	T.B.F.S.a. R.S	1,6	5,17	0,91	0,00	0,00	1,80	0,00	1,60
G18	CISQUERA (NIVEL300)	B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P	1	2,52	0,49	0,00	0,00	0,00	0,00	0,80
G16	VETA GRANDE	M	O.B	F.S	D	T.B.F.S.a. R.S	0,7	9,50	1,36	0,00	1,60	2,40	0,20	5,00
G20	MANTO 2	M	O.B	F.S	D	O.W.S.D.b.R.P	0,7	10,41	0,49	0,00	0,20	2,00	1,40	1,60
G15	BOCATOMA NIVEL 220	M	O.B	F.S	D	T.B.F.S.a. R.S	1,4	8,79	0,57	0,00	0,00	5,60	0,20	1,80
G12	PIEDRO	B.B.Z & S.P.C	O.B	F.S	D	T.B.F.S.a. R.S	0,75	5,93	0,66	0,20	0,00	2,20	0,00	1,80
G08	BOLAS	B.B.Z & S.P.C	O.B	F.S - D.C	D	T.B.F.S.a. R.S	0,7	10,74	0,73	0,00	0,20	2,20	0,40	1,60
G11	CONSUELO SUPERIOR	M	O.B	F.S	D	T.B.F.S.a. R.S	0,75	9,21	0,48	0,00	0,00	1,00	0,20	1,40
G10	CONSUELO	B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P	0,4	10,75	0,41	0,00	0,00	4,60	0,40	4,40
G14	PLANTA DE SODA	M	O.B	F.S	F	T.B.F.S.a. R.S - O.W.S.D.b.R.P	0,2	13,31	0,63	0,00	0,00	10,20	1,40	3,80
G07	GEMELAS	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	1,52	6,47	0,46	0,20	0,00	0,80	1,00	1,20
G03	CUARTAS	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,5	4,41	0,46	0,00	0,00	0,80	0,00	1,60
G09	MILAGROS	W.F.S	O.B (> 2 GI)	F.S	D	O.W.S.D.b.R.P	0,8	4,91	0,50	0,00	0,00	1,20	0,00	1,80
G06	TESORO	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	1,5	10,41	0,34	0,20	0,00	1,60	5,40	1,20
G19	TESORO	M	O.B	F.S	D - F	T.B.F.S.a. R.S	0,7	8,16	0,62	0,00	0,00	2,20	0,20	4,00
G05	TESORITO	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,7	6,75	0,35	0,00	0,00	0,20	0,20	3,80
G17	TESORITO	M - B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	-	5,88	0,57	0,00	0,00	1,20	0,00	4,20
G21	CISQUERA INFERIOR	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,8	3,86	0,40	0,00	0,00	0,00	0,40	0,60

Table 18.

Coal samples with depositional environments and properties (Samacá section).

SAMPLES		DIAGRAMS					FEATURES								
CODE	SEAM	Diessel (1986)	Calder et al. (1991)	Mukhopadhyay (1986)	Singh and Singh (1996)	Singh and Singh (2000)	THICKNESS	ASH	SULFUR	O. PYRITE	I. PYRITE	CLAY MINERALS	FERROUS MINERALS	QUARTZ
SM23	SIETE BANCOS	B.B.Z - M	O.B	F.S	D	T.B.F.S.a. R.S	1,00	12,59	1,82	0,60	1,20	1,80	0,00	2,60
SM04	LA GRANDE	B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P	3.0-1.6	10,32	1,08	0,00	0,00	2,60	0,40	1,20
SM02	LA TERCERA INFERIOR	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,80	5,98	1,55	0,20	0,20	0,20	0,00	0,40
SM01	LA TERCERA SUPERIOR	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,80	4,99	1,12	0,20	0,00	2,60	0,00	0,60
SM03	LA TERCERA (LA LIGADA)	M	O.B	F.S - R.M	D	T.B.F.S.a. R.S	0,90	10,98	1,47	1,20	0,40	3,20	0,00	1,80
SM26	LIGADA	W.F.S	O.B	F.S	D	O.W.S.D.b.R.P	0,85	6,33	1,11	0,20	0,40	0,20	0,20	1,80
SM11	PERDIDA SUPERIOR	B.B.Z	O.B - M.B	F.S	D	T.B.F.S.a. R.S	0,55	4,21	0,60	0,00	0,00	0,20	0,00	1,20
SM12	PERDIDA INFERIOR	B.B.Z - S.P.C	O.B	F.S	D	T.B.F.S.a. R.S	0,40	4,82	0,69	0,00	0,00	1,80	0,20	2,20
SM16	BOCATOMA	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	1,10	5,11	0,49	0,00	0,00	3,00	0,00	2,20
SM05	BOCATOMA	S.P.C - B.B.Z - W.F.S	O.B	F.S	D	T.B.F.S.a. R.S	1,60	4,49	0,46	0,00	0,00	1,00	0,20	0,60
SM06	RUBI	W.F.S	O.B	F.S	D	T.B.F.S.a. R.S	0,92	4,46	0,51	0,00	0,00	0,20	0,40	1,20
SM17	RUBI SUPERIOR	W.F.S	O.B	F.S	D	O.W.S.D.b.R.P (PHOTO)	0,80	6,04	0,55	0,00	0,00	3,60	0,00	0,60
SM18	RUBI INFERIOR	B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P (PHOTO)	0,18	8,50	0,55	0,00	0,00	4,00	2,20	1,80
SM15	PIEDRO SUPERIOR	B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P (PHOTO) (ld cuti)	0,25	8,20	0,62	0,00	0,00	2,20	1,80	0,80
SM07	PIEDRO INTERMEDIO	B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P	0,50	11,95	0,51	0,00	0,00	4,00	1,00	3,40
SM14	PIEDRO MEDIO	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,60	5,83	0,56	0,00	0,00	3,20	0,00	2,40
SM08	PIEDRO INFERIOR	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,56	8,05	0,70	0,00	0,00	6,00	0,80	5,20
SM13	PIEDRO INFERIOR	M	O.B - M.B	F.S	D	O.W.S.D.b.R.P (PHOTO)	0,48	8,42	0,64	0,00	0,00	0,20	0,20	4,20
SM09	CONSUELO SUPERIOR	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,70	8,05	0,57	0,00	0,00	3,20	1,00	0,60
SM10	CONSUELO INTERMEDIO	B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P (PHOTO)	0,70	8,43	0,57	0,00	0,20	2,00	1,80	1,20
SM19	CONSUELO	S.P.C- B.B.Z	O.B	F.S	D	O.W.S.D.b.R.P (PHOTO)	0,80	5,60	0,56	0,00	0,00	2,80	0,00	0,20
SM24	GEMELA SUPERIOR	W.F.S	O.B	F.S - D.C	D	T.B.F.S.a. R.S	0,80	6,62	0,52	0,00	0,00	1,00	0,00	1,00
SM25	GEMELA INFERIOR	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,87	4,46	0,53	0,00	0,00	0,60	0,40	1,00
SM21	TESORO	M	O.B	F.S	F - D	T.B.F.S.a. R.S	0,54	9,15	0,48	0,00	0,00	4,20	0,80	6,40
SM20	TESORITO	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,50	6,54	0,45	0,00	0,00	0,60	2,40	0,60
SM22	CISCUDA (CISQUERA)	B.B.Z	O.B	F.S	D	T.B.F.S.a. R.S	0,90	4,86	0,45	0,20	0,00	0,00	0,00	1,20

LEGEND (Based in the found environments)

Diessel (1986)
BBZ: Back barrier zones
M: Marsh
SPC: Strand plain coal
WTF: Wet forest swamp

Calder et al. (1991)
OB: Ombotrophic bog
MB: Mesotrophic bog

Mukhopadhyay (1986)
FS: Forest swamp
RM: Reed marsh
DC: Dry conditions

Singh and Singh (1996)
D: alternate oxic and anoxic moor
E: Oxic (Dry) moor with sudden high flooding
F: Wet moor with intermittent moderate to high flooding

Singh and Singh (2000)
OWSDbRP: Open water swamp dominated by reed plants
TBFSaRS: Transition between forest swamp and reed swamp

7. CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

The interpretation of the data allows the determination of the rank of coal, paleoenvironments and its relation with the physicochemical properties in the three sections of the Checua-lenguazaque syncline, so for each coal sample were used different diagrams to define the type of vegetation, water level and nutrients.

7.1. CONCLUSIONS

- The Guaduas Formation was deposited in the boundary between The Cretaceous and the Tertiary ages, and it represents a transgressive-regressive cycle. The stratigraphic column presents a clastic sequence with an important accumulation of organic matter evidenced in the presence of coal seams (14 seams approximately).

- The regional geological structure where is found the Guaduas Formation is the Checua-Lenguazaque syncline (Boyacá and Cundinamarca provinces), this one was divided in three sections, Sutatausa, Guachetá and Samacá; where the coals seams where studied to analyze the vertical and lateral changes (13 seams from Sutatausa, 17 seams from Guachetá and 14 seams from Samacá).

- The random reflectance of vitrinite increases wit depth, so the peak temperature of each coal was higher in the base of the stratigraphic column. The results indicated that the zone had different paleogeothermal gradients, 52°C/Km for Sutatausa, 82°C/Km for Guachetá and 100 °C/Km for Samacá; in a rank of temperature from 105°C to 173°C.

- The predominant maceral group in the samples was the vitrinite group with content between 51.40% and 87.00%; followed by the inertinite group with content from 5.40% and 43.80%. Macerals of the Liptinite group and mineral matter presented minor proportion in comparison with the other maceral groups, 0.20% and 14.00 % and 0.40% and18.00% respectively.

- The results from test showed that coals from Checua-lenguazaque syncline have different Rank along the stratigraphic column. According with the ASTM D388-12 norm, the coals were classified as high volatile to low volatile bituminous coals increasing the rank with depth; using the ISO 11760 norm, the coals were classified as bituminous coals type C to A, so the Sutatausa section are present coals with lower rank than coals from other two sections.

- The correlation between reflectance of vitrinite and volatile matter has an inverse relation, when the average random reflectance of vitrinite increases, the volatile matter decrease which is normal during the coalification process, however coals with reflectance of vitrinite of 1.1 - 1.2% are not present coinciding with the deposition of the “key bed 1”. The relation between ash and mineral matter is direct and it represents the proportion mass-volume of the inorganic content in the coals.

- The coals from the Checua-lenguazaque syncline present low values of TPI due the high content of collodetrinite formed in environments with high PH and transporting of particles (Jiménez , et al., 1999), (Guatame & Sarmiento, 2004), (Mejia Umaña, et al., 2006), so the coals were deposited mainly in marshes and back barrier zones followed by wet forest swamps and strand plains. The high values of GI indicate a high level of water as product of marine incursions. The diagram blocks for each section are presented in the figures 41, 42 and 43 evidencing a trend to wet forest swamps in the Sutatausa section (Figure 41) which is related with an increase of collotelinite.

- The model proposed by Calder, et al. (1991) was used to determine the origin of nutrients in the peat bog and the precursor vegetation of which coal comes. The results indicated that all samples were deposited in ombotrophic condition in marginal bogs, however in the Sutatausa section there is a mesotrophic tendency related with the high content of mineral matter (Ash) in some samples.

- The ternary diagram proposed by Mukhopadhyay (1986) showed a clear tendency to D zone (Forest swamp, mildly oxic to anoxic with good tissue preservation). Some coals of the Sutatausa section presented a tendency to E zone due there is major maceration of the organic constituents formed in reed marshes while the coals from Guachetá and Samacá section presented a tendency to dry conditions.

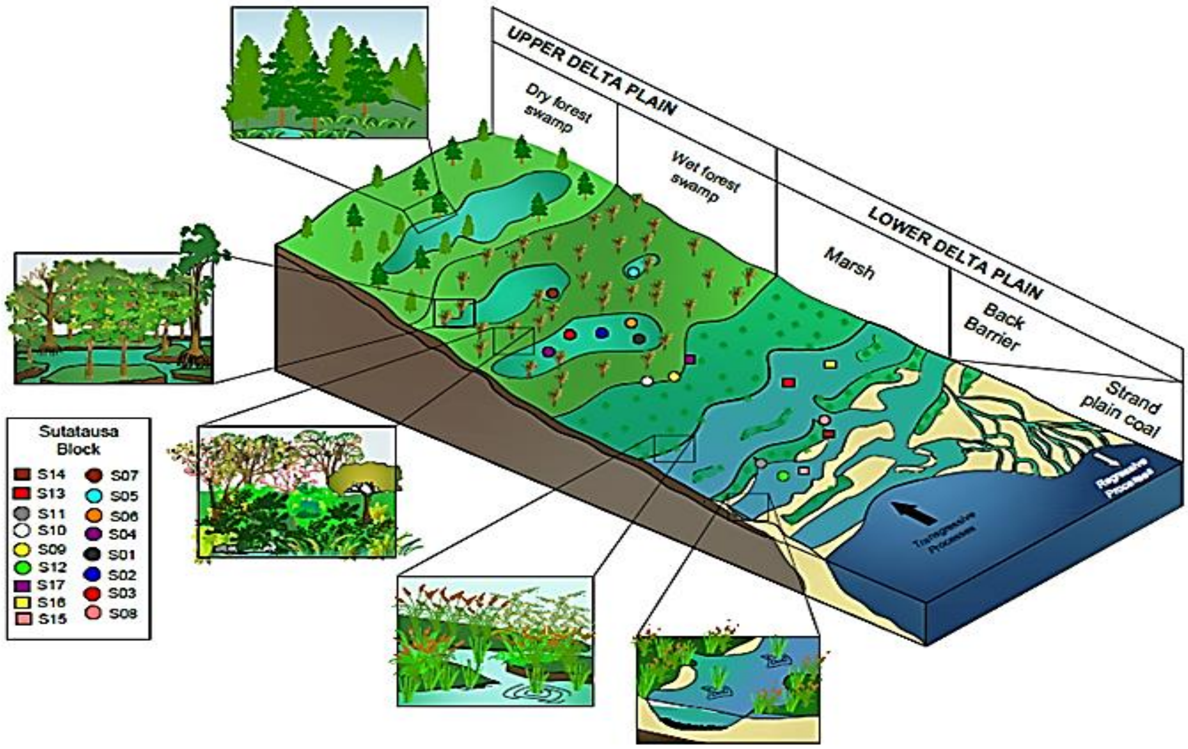

Figure 41. Diagram block for depositional environments. Sutatausa section.

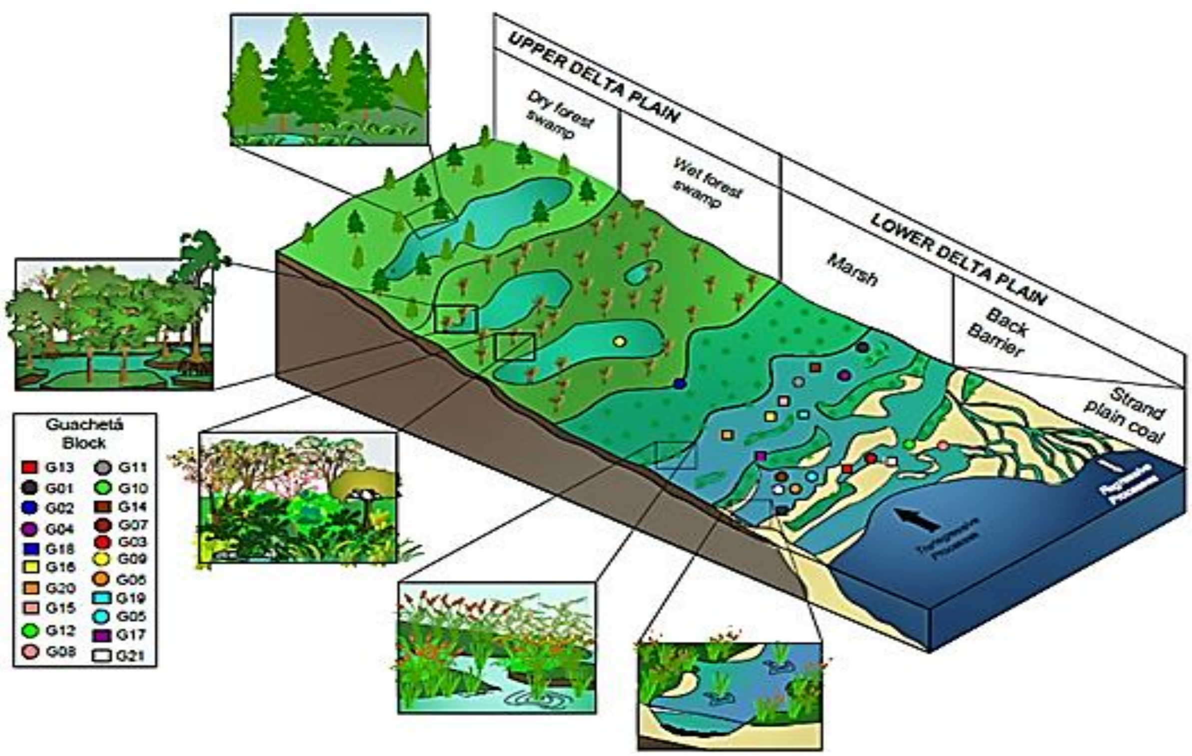

Figure 42. Diagram block for depositional environments. Guachetá section.

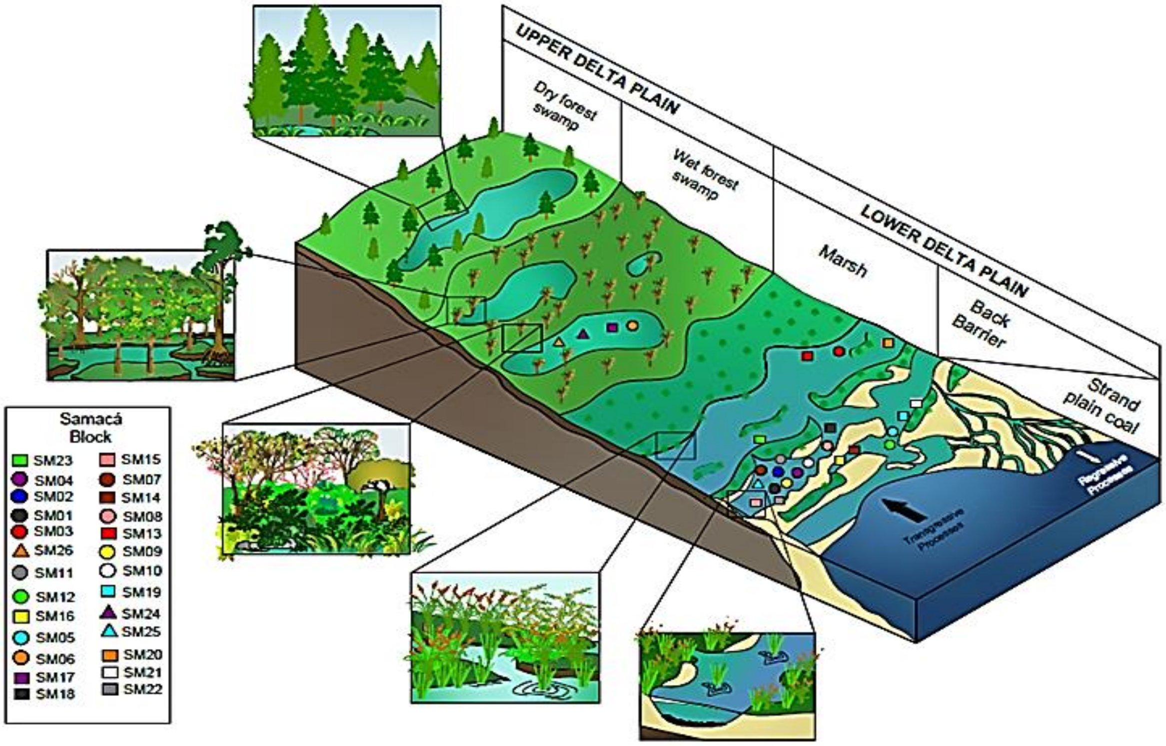

Figure 43. Diagram block for depositional environments. Samacá section.

- The diagram modified by Singh & Singh (1996) from Goodarzi (1985) gives the importance of mineral matter in the deposition of organic components during the peat stage; so all samples presented a tendency to the D zone (Alternate oxic and anoxic moor) due the high content of vitrinite; however the Planta de Soda and Suncho Cisquera seams in the Guachetá section and the Tesoro seam in the Samacá section were deposited in wet moors with greater influx of flooding due the content of mineral matter.

- The ternary diagram proposed by Singh & Singh (2000) using the macerals of the liptinite group to determine the water depth and the kind of vegetation, for the sampled coals there were a disposition to the B and C zones due the intermittent content of resinite as signal of tree vegetation; this diagram presented a problem due to the low content of macerals of the liptinite group in the studied samples, thus some samples were interpreted using the photographic record; this decrease in the content of this maceral group is directly related with the high rank of these coals which it is evidenced in the stratigraphic column.

- The diagram proposed by Misiak (2002) represents the importance of water level in the formation of coal, so the presence of the maceral groups depends directly of the water surface in the peat bog, in this way long-lasting periods of inundation and drying of the mire enforced a gradual change of its plant assemblage (Misiak J. , 2006). The coals from the Checua-Lenguazaque syncline were deposited in planar mires (Permanently inundated) and transitional mires (Temporarily inundated) with their associated subenvironments. The Sutatausa section has a trend to a higher water level (Figure 44) according with the content of mineral matter while the Guachetá and Samacá sections present a drier condition due the high content of inertinite (Figures 45 and 46) presenting an elevated mires tendency, so "relatively short-lasting oscillations of the water level did not need to enforce succession of vegetation if they took place within the ecological amplitude of a given plant assemblage and the changes caused by them were minor, as reflected in the maceral composition" (Misiak J. , 2006, p. 122), for this reason is variable the content of the collotelinite and collodetrinite evidencing different kind of vegetation.

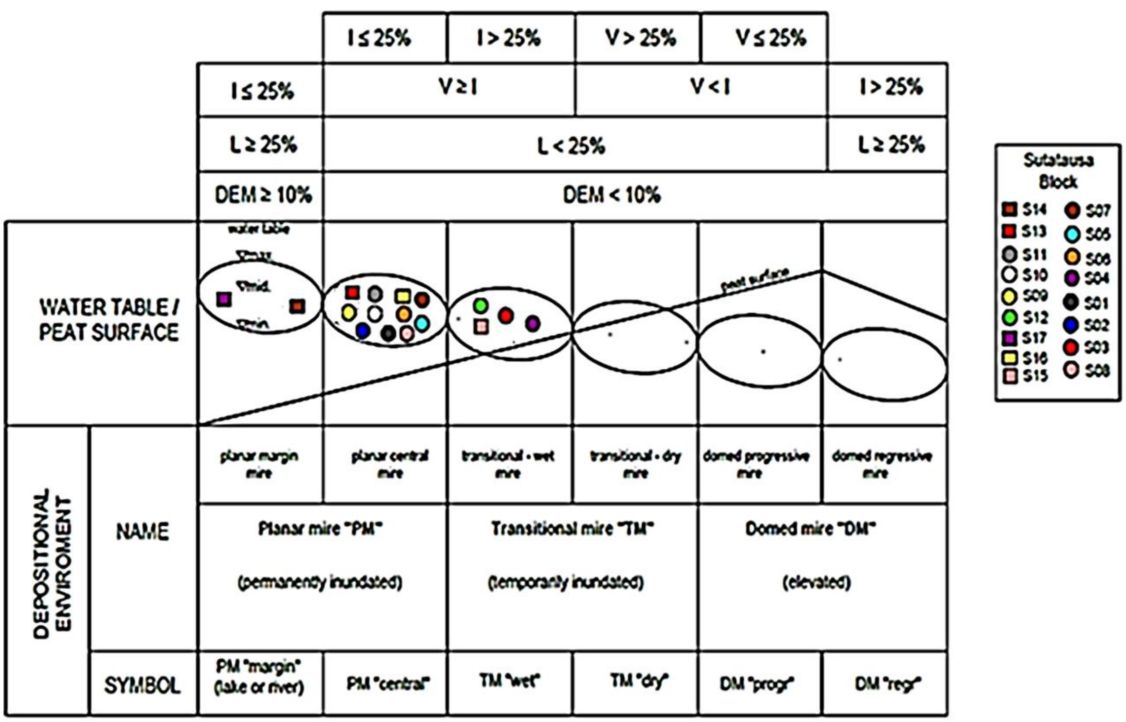

Figure 44. Sedimentary environments in the Sutatausa block, (Modified from Misiak J. (2002)) (DEM–detrital matter, I–inertinite, L–liptinite, V–vitrinite).

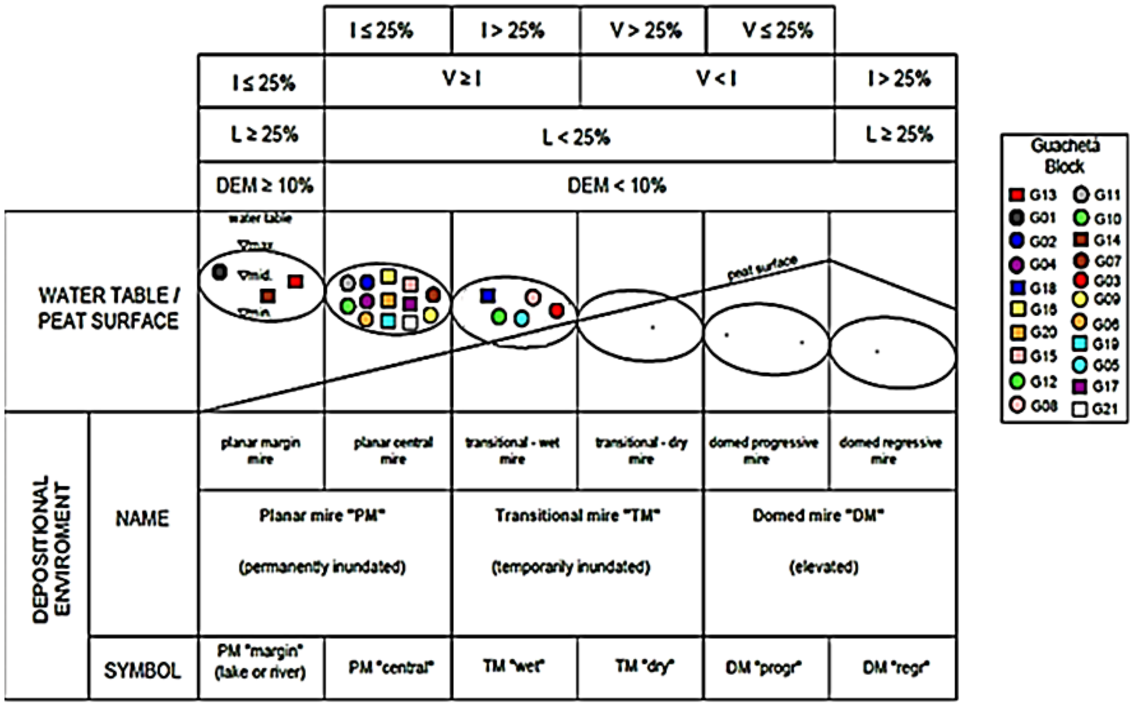

Figure 45. Sedimentary environments in the Guachetá block, (Modified from Misiak J. (2002)) (DEM–detrital matter, I–inertinite, L–liptinite, V–vitrinite).

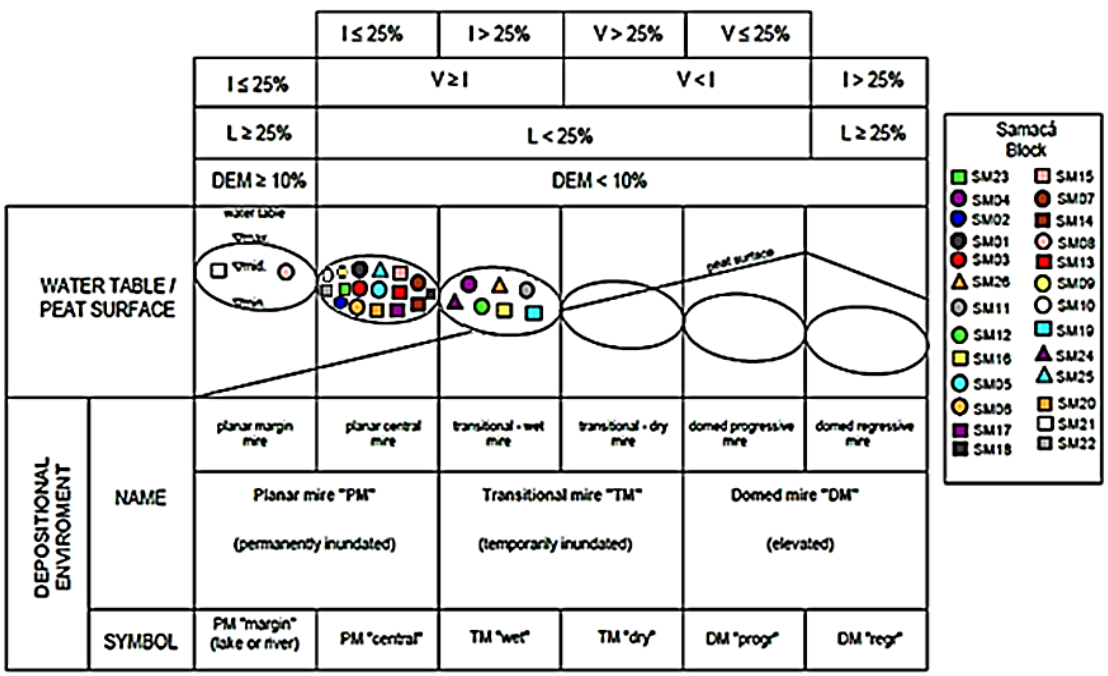

Figure 46. Sedimentary environments in the Samacá block, (Modified from Misiak J. (2002)) (DEM–detrital matter, I–inertinite, L–liptinite, V–vitrinite).

- The diagram proposed by Misiak (2003) is other way to show the importance of mineral matter in coal composition, so when there is a high level of water the process of gelification was intensive, reflected in a high content of the vitrinite group macerals suggesting that mineral matter was deposited in basins susceptible to degradation in a inundated mire (Mastalerz, Padgett , & Eble Cortland, 2000) , while a low water is manifested in the increase of macerals of the inertinite group, so oxidation is also indicated by an increase of the liptinite group macerals in coal during degradation of the plant material; content of mineral matter <5.00% is associated with the degradation of tissues while a content >5.00% reflects the influx of water into the mire and a content >10.00% is associated with fluvial systems (Misiak J. , 2006). The figures 47, 48 y 49 shows the depositional environments for the studied coals according with the water influx, here is evident as the Deposito and La Grande 2 seams in the Sutatausa section; 7 Bancos, Suncho Cisquera and Planta de soda in Guachetá and; Piedro Inferior and Tesoro in the Samacá section had major influence of detrital material as product of fluvial action.

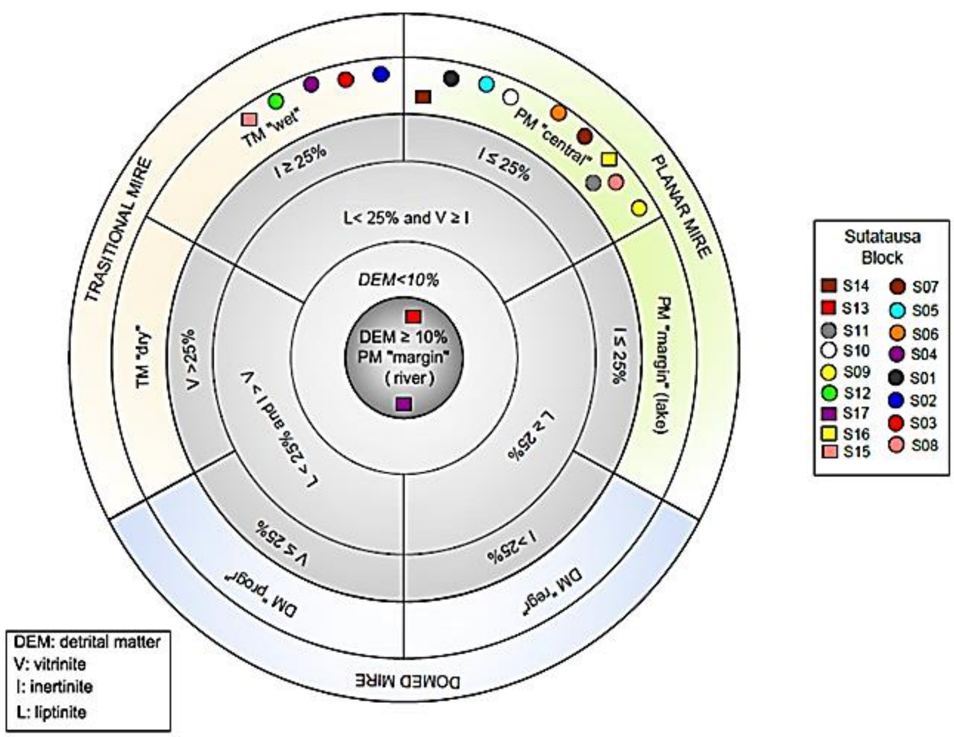

Figure 47. Diagram of the coal facies analysis, Sutatausa section (Modified from Misiak J. (2003)).

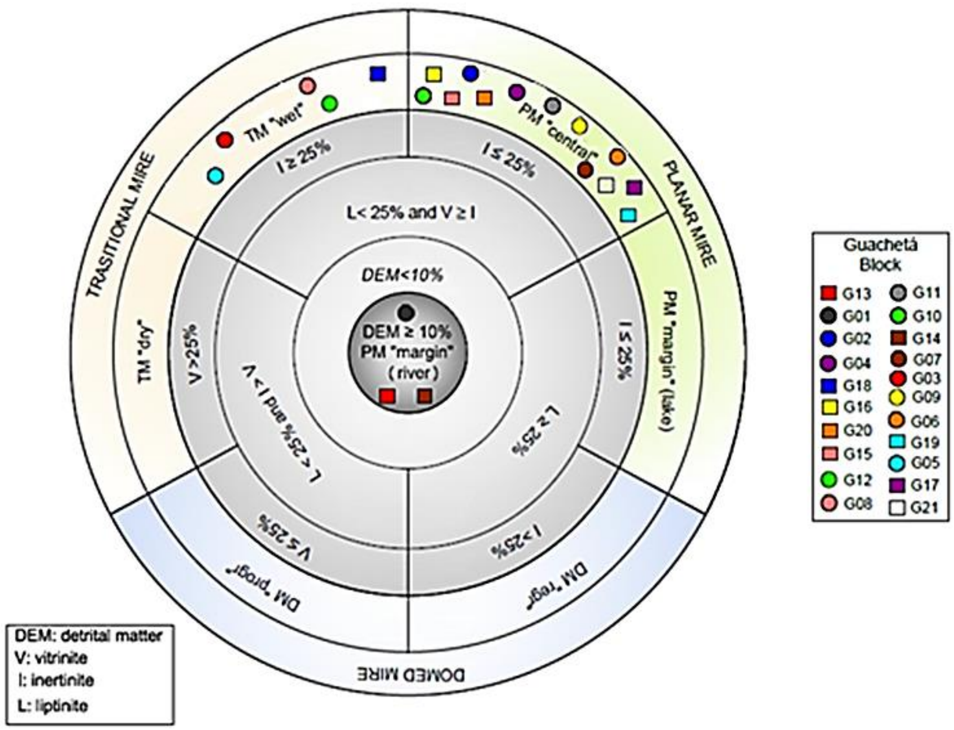

Figure 48. Diagram of the coal facies analysis, Guachetá section (Modified from Misiak J. (2003)).

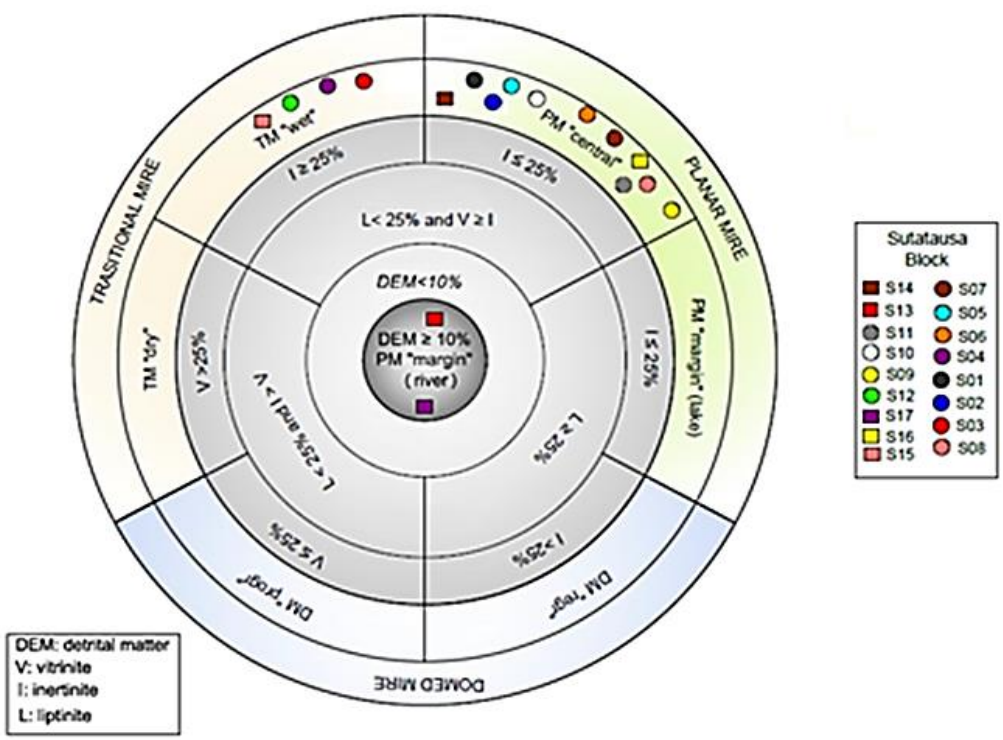

Figure 49. Diagram of the coal facies analysis, Samacá section (Modified from Misiak J. (2003)).

- Coals with percentages of ash up 10.00% were deposited in marshes and back barrier zones, which is related with the marine incursions in the moment of deposition favoring the degradation of organic matter. The coals deposited in marshes presented more of 8.00% in ash with predominance of clay minerals and quartz and disperse relation between ash and sulfur indicates that sulfur in mainly of organic type.

- In the interval 250 – 350 m there is an important change in the properties of coals in the three sections of the Checua-lenguazaque syncline evidencing a facies change and the deposition of the “key bed 1”. Other important aspect is the increase of ash, sulfur and moisture in the upper part of the stratigraphic columns where the regressive events are more constant.

7.1. RECOMMENDATIONS

- Make more stratigraphic columns to determine lateral changes of the coals (Physicochemical properties, reflectance of vitrinite and maceral composition), establish correlations and determine environments with lithostratigraphy (Detailed description of sedimentary structures). Extend the study to the municipalities of Lenguazaque, Tausa, Cucunuba and Ráquira; and determine the proportion of lithotypes in the coal samples.

- Make microlithotypes test to tie the information obtained with the maceral composition and to determine another type of environmental conditions in the formation of the coal seams (Microlithotype composition of coals, facies diagram proposed by Hacquebard and Donaldson 1969) (Diagram of environments of coal deposition related to microlithotype composition of coals proposed Smyth, 1979).

- Measure the reflectance of the macerales of the inertinite group to define its origin, since this value can evidence if the oxidation was product of the sub aerial exposure or forest fires.

- Make chemical tests on the ashes to obtain the elements present and define if their origin is terrestrial or marine and apply different techniques to separate the trace elements in the studied samples.

8. BIBLIOGRAPHY

Alves, R. G., & Ade, M. B. (1996). *Sequence stratigraphy and coal petrography applied to the Candiota Coal Field, Rio Grande do Sul, Brazil: A depositional model.* International Journal of Coal Geology 30 231-248.

Amaya Medina, E. J. (2009). *Litofacies y ambiente de acumulación de la Formación Guaduas.* Sogamoso, Boyaca, COL: UPTC.

Barker, C. E., & Pawlewicz, M. J. (1994). *Calculation of Vitrinite Reflectance from Thermal Histories and Peak Temperatures A Comparison of Methods.* Washington D.C, USA: ACS Symposium Series, Vol. 570.

Barrera Ponguta, J. A. (2016). *Determinación de la madurez térmica de los carbones de la Formación Guaduas en el sinclinal Checua-Lenguazaque.* Sogamoso, BOY, COL: UPTC.

Boggs, S. J. (2006). *Principles of Sedimentology and Stratigraphy.* New Jersey, USA: Pearson Education, Inc.

Buillit, N. E., Lallier, B., Nicolas, G., & Pradier, B. (2002). *Coal petrographic genetic units in deltaic-plain deposits of the Campanian Mesa Verde Group (New Mexico, USA).* International Journal of Coal Geology, v. 51 (2), p. 93-110.

Calder, J. H., Gibbing, M. R., & Mukhopadhay, P. K. (1991). *Peat formation in a Westphalian B pidemont setting, Cumberland Basin, Nova Scotia: implication for the maceral-based interpretation of rheotrophic and raised paleomires.* Bull. Soc. Geol. Fr. 162, 283–298.

Cooper, M. A., Addison, F. T., Alvarez, R., Coral, M., Graham, R. H., Hayward, A. B., . . . Tobon, A. (1995). *Basin Development and Tectonic History of the Llanos Basin, Eastern Cordillera, and Middle Magdalena Valley, Colombia.* A.A.P.G Bulletin , 1421-1443.

Diessel, C. F. (1986). *The correlation between coal facies and depositional environments. In: Advances in the Study of the Sydney Basin.* Proc. 20th Syrup., Newcastle, N.S.W., pp. 19-22.

Duarte B., C., & Parra C., F. (2012). *Exploración Gas Metano Asociado al Carbón.* Servicio Geológico Colombiano.

Duarte Barrera, C. i., Monroy V., W. O., & Rincón, M. A. (2012). *EXPLORACIÓN GAS METANO ASOCIADO AL CARBÓN. ÁREA CHECUA*

CHECUALENGUAZAQUE. Bogotá, CUN, COL: SERVICIO GEOLÓGICO COLOMBIANO.

Etayo, F., Renzoni, G., & Barrero, D. (1969). *Contornos sucesivos del mar Cretaceo en Colombia.* Bogota, Cundinamarca, COL: Primer congreso Colombiano Geol. Mem 217-252.

Fabre, A. (1985). *Dinamica de la sedimentacion Cretacica en la Sierra Nevada del Cocuy. (Cor. Ori. Col) Proyecto cretacico.* Bogotá, Cundinamarca, COL: Publi. Geol. Esp. no 16 Ingeominas.

Gomez Neita, J. S., Lopez Carrasquilla, M. D., Manosalva Sánchez, S. R., & Naranjo Merchán, W. E. (2016). *APORTES A LA DETERMINACIÓN DE PALEOAMBIENTES, CARBONES DEL SINCLINAL CHECUA-LENGUAZAQUE. COLOMBIA.* Sogamoso, BOY, COL: Revista Ingeniería, Investigación y Desarrollo.

Goodarzi, F. (1985). *Organic petrology of Hat Creek Coal deposit No. 1, British Columbia.* Int. J. Coal Geol., 5: 377-396.

Guatame, C. L., & Sarmiento, G. (2004). *Interpretación del Ambiente Sedimentario de los Carbones de la Formación Guaduas en el Sinclinal Checua-Lenguazaque apartir del análisis petrográfico.* Bogotá, CUN, COL: Geología Colombiana No. 29.

Horne, J. F. (1978). *Depositional models in coal exploration and mine planning in Appalachian region. .* AAPG Bulletin 62, 2379–2411.

Hubach, E. (1957). *Estratigrafía de la sabana de Bogotá y sus alrededores.* Bogotá, Cundinamarca, COL: Bol. Geol., Serv. Geol. Nal., 5 (2): 93-112.

INGEOMINAS, C. C. (1992). *CARACTERISTICAS Y USOS TECNOLOGICOS CARBONES CUNDINAMARCA BOYACA.* CARTOGRAFÍA INGEOMINAS.

ISO, 1. (2005). *Classification of coals.* The International Organization for Standardization.

Jiménez , A., Martinez Tarazona, R., & Suárez Ruiz, I. (1999). *Paleoenvironmental conditions of Puertollano coals (Spain): petrological and geochemical study.* International Journal of Coal Geology, v. 41 (3), p. 189-211.

Laverde, F. (1979). *Espesor, estratigrafía y facies de la Formación Guaduas en algunos sitios del cuadrangulo K-11. Tesis de grado universidad Nacional de Colombia.* Bogotá, Cundinamarca, COL: Ingenominas, 1-92.

Mastalerz, M., Padgett , L., & Eble Cortland, F. (2000). *Block coals from Indiana: inferences on changing depositional environment.* International Journal of Coal Geology, v. 43 (1-4), p. 211-226.

Mejia Umaña, L. J., Convers Gomez , C. E., & Gonzales Casallas, J. F. (2006). *Análisis de Microlitotipos en los Carbones de la Formación Guaduas en el Sinclinal de Sueva, Cundinamarca.* Bogotá, CUN, COL: Geología Colombiana No. 31.

Misiak, J. (2002). *Środowiska depozycji materii organicznej w torfowiskach karbońskich. Mat. XXV Symp. nt. Geologia formacji węglonośnych Polski.* Wyd. AGH, Kraków, pp. 105–108.

Misiak, J. (2003). *Projekt diagramu do analizy facjalnej pokładów węgla kamiennego. Mat. XXIV Symp. nt. Geologia formacji węglonośnych Polski.* Wyd. AGH, Kraków, pp. 109–113.

Misiak, J. (2006). *Petrography and depositional environment of the No. 308 coal seam (Upper Silesian Coal Basin, Poland)—a new approach to maceral quantification and facies analysis.* International Journal of Coal Geology 68. 117–126.

Mukhopadhyay, P. K. (1986). *Petrography of selected Wilcox and Jockson Group lignites from Tertiary of Texas. In: Finkelman, R.B., Casagrade, D.J. Eds.., Geology of Gulf Coast Lignites.* Annu. Meet. Geol. Soc. Am., Coal Geol. Div. Field Trip, pp. 126–145.

Nowak, G., & Nowak, A. G. (1999). *Peat-forming environments of Westplain A coal seams from the Lower Silesian Coal Basin of SW Poland based on petrographic and palynologic data.* International Journal of Coal Geology, v. 40, p. 327-351.

Ryan, B., Gransden, J., & Price, J. (1997). *Fluidity of western canadian coals and its relationship to other coal and coke properties.* Canadá: British Columbia Geological Survey.

Sarmiento Pérez, G. (1991). *Estratigrafia y medios de deposito de la Formación Guaduas.* Bogotá, Cundimarca, COL: Ingeominas, Bol Geol, Vol 32, N° 1-3.

Sarmiento, G. (1992). *Palinología de la Formación Guaduas (Estatigrafica y Sistemática).* Bogotá, Cundinamarca, COL: Boletin Geológico No 32, p 45-126.

Sarmiento-Rojas, L. F., Van Wess, J. D., & Cloe, S. (2006). *Mesozoic transtensional basin history of the Eastern Cordillera,Colombian Andes: Inferences from tectonic models.* Journal of South American Earth Sciences 21, 383–411.

Singh, M. P., & Singh, A. K. (2000). *Petrographic characteristics and depositional.* Varanasi, IN.

Singh, M. P., & Singh, P. K. (1996). *Petrographic characterization and evolution of the Permian coal deposits of the Rajmahal Basin, Bihar, India.* Int. J. Coal Geol. 29, 3–118.

Stach, E., Mackowsky, M. T., Teichmuller, M., Taylor , G. H., Chandra, D., & Teichmuller, R. (1982). *Stach's Textbook of Coal Petrology.* Berlin, GER: 3rd edn. Gebruder Borntraeger,535 pp.

STANDARDS, A. (2016). *Annual Book of ASTM Standards.* Gaseous Fuels: Coal and Coke.

Suarez Ruiz, I., & Crelling, J. C. (2008). *Applied Coal Petrology, The Role of Petrology in Coal Utiliztion.* Burlington, MA USA: Academic Press.

UPME, U. d. (2012). *Cadena del Carbon.* Republica de Colombia, ministerio de minas y energia.

Vessey, S. J., & Bustin, R. M. (2000). *Sedimentology of the coal-bearing Mist Mountain Formation, Line Creek, Southern Canadian Cordillera: relationships to coal quality.* International Journal of Coal Geology 42. 129–158.

9. APPENDICES

(Annex)

- Stratigraphic columns with properties of the sampled coals.
- Geological map.